Edible insects—a novel source of essential nutrients for human diet: Learning from traditional knowledge

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Introduction

Edible insects are an important source of food for humans, with more than 1,900 species reported as being edible at some stage of their life cycle (Belluco et al., 2013; van Huis et al., 2013). A wide variety of insects’ species have been consumed as traditional foods by many indigenous communities, especially in Africa, Asia, and Latin America (Kinyuru et al., 2009, 2013; Makkar et al., 2014). These communities have developed their skills and techniques in harvesting, preparing, consuming, and preserving edible insects, widely contributing to the role played by the use of insects in human nutrition. It is estimated that more than 2 billion people commonly eat different types of insects globally (Belluco et al., 2013; van Huis et al., 2013).

Globally, food and nutrition insecurity is a function of massive challenges of an ever-increasing human population,1 climate change, and inadequacies in food production and distribution facing the world (Gelsdorf, 2011). It is estimated that by 2050, the consumption of animal products will increase by approximately 60 to 70%, especially from developing countries due to shifts in dietary habits (Ayieko et al., 2012; Makkar et al., 2014; Smith and Pryor, 2013). The food insecurity situation being experienced is also as a result of urbanization, increasing incomes, nutritional and environmental elements among other anthropogenic concerns that put immense pressure on national, regional, and global food systems (Rosegrant and Cline, 2003). This situation is likely to persist in the next decade, requiring a proportionate increase in food production, distribution, and a widening of food options to satisfy the growing food demand for the projected 8 to 9 billion people in the world (Maxwell, 1996; Pinstrup-Andersen and Pandya-Lorch, 1998).

To ensure food security as well as preservation of the natural habitats, research on diversification of food sources has been conducted and explored widely, with the utilization of insects for nutrition being proposed as a possible solution (Belluco et al., 2013; van Huis et al., 2013). Therefore, more attention is currently being drawn toward entomophagy. This novel potential strategy can radically change the trend of malnutrition and other nutritional deficiencies as well as improve the overall food and nutrition security, particularly in the developing regions that are the hardest hit (Maxwell, 1996; Kinyuru et al., 2013; Makkar et al., 2014). This is because different studies have shown that entomophagy contributes positively to nutrition and health, the environment, and livelihoods of those involved in the edible insects value chain (van Huis et al., 2013).

Insects grow and reproduce quickly, have a high growth and feed conversion2 efficiency, can be reared on bio-waste streams, and have a low environmental footprint over their entire life cycle. Moreover, they also emit fewer greenhouse gases and may pose less risk of transmitting zoonotic infections to humans (Ayieko et al., 2012; Makkar et al., 2014). The gathering and rearing of insects offer suitable opportunities for livelihood

1 The global human population is projected to be more than 9 billion people in 2050.
2 Insects have high feed conversion efficiency because they are cold blooded. Thus, they have more efficient feed-to-meat conversion rates than conventional livestock (van Huis et al., 2013).
diversification because the technical and capital expenditures required for harvesting and rearing equipment are minimal. Therefore, a large number of individuals can easily be involved in different stages of the value chain, thus having a direct impact on the cash income and the diets of those involved in the activities (van Huis et al., 2013). Table 1 shows the most commonly consumed insects globally in terms of proportions.

Edible insects are highly nutritious and are a suitable source of essential nutrients required in the human diet. The nutrients are also easily assimilated by the human body (Ayieko et al., 2012; van Huis et al., 2013). They are particularly rich in digestible proteins, fat, and a range of micronutrients (Kinyuru et al., 2009; Kinyuru et al., 2013; Makkar et al., 2014). Insects are usually not consumed as emergency food during shortages as commonly perceived. For instance, 5 to 10% of the protein consumed in some African communities is derived from a variety of edible insects (van Huis et al., 2013). Therefore, edible insects are a suitable alternative source of food nutrients, and their use on a wide scale should be encouraged, especially in sub-Saharan Africa where chronic or seasonal shortage of vertebrate food reserves is still common (Kinyuru et al., 2010; Ayieko et al., 2012).

Entomophagy depends on the availability of edible insects and the ability to trap them as well as the cultural beliefs and customs of those consuming them (Ayieko and Millicent, 2010; Kinyuru et al., 2010; Konyole et al., 2012). The management of insects as a sustainable source of nutrition requires better methods to ensure organized and controlled large-scale production and processing of insects as mini livestock to improve their conservation (Ayieko et al., 2011; Makkar et al., 2014). This is essential because some species of edible insects have recently experienced a sharp decline in their populations as a result of various anthropogenic factors including overharvesting, pollution, and habitat degradation (Ayieko et al., 2011). Therefore, this calls for the merging of modern science with the invaluable traditional knowledge and food culture in the development of innovations and scaling up of mass-rearing and processing technologies of edible insects without affecting the wild insect population (van Huis et al., 2013). This review focuses on the nutritional value of edible insects to explain their importance as a source of nutrients in human nutrition and to promote insects as a healthy alternative food option.

### Nutritive Value of Edible Insects

Edible insects are rich in essential nutrients, but their nutritional value varies greatly depending on the species, stage of life, habitat, and diet of the insect. Moreover, the nutritional composition of the edible insects is

<table>
<thead>
<tr>
<th>Order</th>
<th>Examples</th>
<th>%</th>
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<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coleoptera</td>
<td>Beetles</td>
<td>31</td>
<td>Isoptera</td>
<td>Termites</td>
<td>3</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>Caterpillars</td>
<td>18</td>
<td>Odonata</td>
<td>Dragonflies</td>
<td>3</td>
</tr>
<tr>
<td>Hymenoptera</td>
<td>Bees, wasps and ants</td>
<td>14</td>
<td>Diptera</td>
<td>Flies</td>
<td>2</td>
</tr>
<tr>
<td>Orthoptera</td>
<td>Grasshoppers, locusts and crickets</td>
<td>13</td>
<td>Others (Dictyoptera, Mega-</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Hemiptera</td>
<td>Cicadas, leafhoppers, planthoppers, scale insects and true bugs</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Source: Van Huis et al., 2013.

3 Stage of life refers to the metamorphic stage of an insect is in its life cycle.
also affected by the preparation and processing methods applied before consumption (Kinyuru et al., 2009; Van Huis et al., 2013). According to FAO (Van Huis et al., 2013), different studies have assessed the nutritive value of edible insects, but they are not always directly comparable due to variations of the insect species and in the analytical methodologies employed. However, the International Network of Food Data Systems (INFOODS) and FAO are working to streamline food composition and consumption data with an aim of promoting dietary biodiversity. The first INFOODS Food Composition Database for dietary biodiversity was launched in 2010, and it included nutritional composition of several edible insects.

**Proteins and amino acids**

The protein content of insects is quite high, but there are wide variations across different species (Belluco et al., 2013; van Huis et al., 2013). These findings report the protein content of different raw edible insect species in the range of 7 to 48% of fresh weight compared with the protein content of raw beef, cooked reptiles, and raw fish and seafood, which were in the range 19 to 26%, 11 to 27%, and 13 to 28% of fresh weight, respectively. Besides, in another study, the protein content of dried caterpillars was found to be similar to beef (Bauserman et al., 2013). In a report commissioned by FAO in 2013 that evaluated different studies analyzing various insect species, the crude protein content was found to range between 13 and 81% of dry matter (van Huis et al., 2013). However, the type of feed consumed by an insect and the stage of metamorphosis are the main determinants of protein content. Besides, there is a plethora of evidence that protein content is usually greater in adults than in instars (Belluco et al., 2013).

Insect proteins have been found to be highly digestible. The protein digestibility of 78 species evaluated in Mexico ranged from 76 to 98% (Belluco et al., 2013). The essential amino acid score from the analysis of 78 species of edible insects ranged from 46 to 96% compared with the recommended score of ≥40% for human diet (Smith and Pryor, 2013). The processing/preservation methods used have an effect on both the protein content and its digestibility (Kinyuru et al., 2009; Van Huis et al., 2013). Generally, insects have a high protein content that is also very digestible and of high quality, which can aid in improving nutritional quality, especially when used as an alternative to animal source proteins.

Various plant source proteins, especially cereal proteins, which are key staples in diets all over the world, are often low in a number of essential amino acids or even lack some of them altogether. For instance, most cereals are low in lysine and may lack tryptophan (maize) or threonine (van Huis et al., 2013). However, these essential amino acids are found in sufficient amounts in some insect species. According to van Huis et al. (2013), lysine amino acid scores greater than 100 mg per 100 g of crude protein can be found in palm weevil larvae, aquatic insects, and a number of caterpillars of the Saturniidae family. The termite species *Macrotermes bellicosus* is rich in tryptophan and lysine, and it can easily be used to manage their deficiencies, which are common in countries where maize is a staple. Therefore, edible insects can be recommended for use as enrichment of foods in cereal-based diets (van Huis et al., 2013).

**Micronutrients**

Minerals and vitamins play vital roles in different metabolic processes in the body. They are usually not synthesized in the body, although some vitamins are produced but in quantities insufficient to support life. Micronutrient deficiencies are common in developing countries and can lead to adverse health consequences, such as growth stunting, which cannot always be reversed by nutritional interventions (Bauserman et al., 2013). The WHO has recommended complementary feeding using foods from animal sources to avoid micronutrient deficiencies (WHO and UNICEF, 2003). Because animal-source foods are insufficient and/or unaffordable in many areas of the world, insects can be used as an alternative in the diets. Mineral and vitamin contents of edible insects vary greatly across the

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4 Turtle species that were analyzed were *Chelodina rugosa* and *Chelonia depressa*.

5 Types of fish and seafood that were analyzed were tilapia, mackerel, catfish, lobster, prawn (Malaysia), shrimp, cuttlefish, and squid.
different insect species. Greater micronutrient contents can be provided by consuming an entire insect as opposed to consuming insect parts only (Smith and Pryor, 2013; van Huis et al., 2013).

**Minerals**

Many edible insects are rich sources of iron and usually have equal or greater iron contents compared with beef. For instance, the iron contents for mopane caterpillar and locusts (*Locusta migratoria*) range from 31 to 77 mg and 8 to 20 mg per 100 g of dry weight, respectively, as compared with that of beef of 6 mg per 100 g of dry weight (van Huis et al., 2013). According to Kinyuru et al. (2013), termites are rich sources of iron and zinc (Table 2). The WHO lists iron deficiency as one of the world’s most widespread nutritional disorders, and anemia is highly prevalent among pregnant women and preschool children in developing countries. The deficiency contributes to 20% of all maternal deaths even though it is preventable. Therefore, considering their high iron contents, the inclusion of edible insects in the daily diet needs to be exploited, as a way of improving the iron status (Kinyuru et al., 2013).

Zinc deficiency is similarly a great health challenge especially to child and maternal health. The deficiency causes defects in the immune system leaving the body vulnerable to other health consequences. However, most insects are also good sources of zinc. For example the palm weevil larvae was found to contain 26.5 mg of zinc per 100 g of dry weight compared with beef, which averaged 12.5 mg per 100 g of dry weight (van Huis et al., 2013). Other reports on contents of zinc and iron in various insects generally indicate that they are rich in these minerals (Christensen et al., 2006). In addition, these findings suggests that bioavailability of these minerals from the insects is likely to be greater than from the plant foods (Christensen et al., 2006).

**Vitamins**

Most edible insects are a suitable source of different types of vitamins essential to the human body. A range of insects were evaluated by van Huis et al. (2013) who showed that the content of thiamin (vitamin B₁) and riboflavin (vitamin B₂) ranged from 0.1 to 4 mg and 0.11 to 8.9 mg per 100 g of dry weight, respectively compared with, for example, wholemeal bread, which provides 0.16 mg and 0.19 mg per 100 g dry weight of vitamins B₁ and B₂, respectively. Vitamin B₁₂ is only obtained from foods of animal origin. The vitamin has been found in various species of edible insects like the mealworm larvae (0.47 mg per 100 g) and house crickets (5.4 mg per 100 g in adults and 8.7 mg per 100 g in nymphs) (Finke, 2002; Bukkens and Paoletti, 2005). Exceptionally high quantities of vitamin E have been found in the palm weevil larvae, which had 35 mg and 9 mg per 100 g of dry weight of α-tocopherol and β + γ tocopherol, respectively (Finke, 2002; Bukkens and Paoletti, 2005). Kinyuru et al. (2009) reported α-tocopherol in long-horned grasshopper (*Ruspolia differens*) in the range of 161 mg/100 g to 170 mg/100 g on a dry weight basis. Both retinol and β-carotene have been found in some caterpillar species ranging from 32 to 48 mg per 100 g and 6.8 to 8.2 mg per 100 g of dry weight, respectively. The vitamin was also detected in yellow mealworm larvae, superworms, and house crickets, but the levels were less than 20 and 100 mg per 100 g of dry weight for retinol and β-carotene, respectively (Finke, 2002; Bukkens and Paoletti, 2005).

**Lipids and fatty acids**

Edible insects are considered to be a rich source of fats. For example, the witchetty grub found in Australia has a high fat content of 38% of dry weight. Table 3 shows the fat content of different insect species consumed in Cameroon.

The edible insects have been found to be rich in polyunsaturated fatty acids, which frequently contain essential fatty acids (some omega-6 and omega-3 fatty acids). Kinyuru et al. (2013) and van Huis et al. (2013) analyzed four species of winged termites and found the n-6:n-3 ratios in the range 5.8:10 to 57.7:10, showing that insects offer high quality fat in the diets of communities consuming them (Table 4). Most insects have polyunsaturated/saturated fatty acid ratios greater than 0.20, which is associated with low cholesterol levels, and thus is associated with less risk for certain coronary heart diseases (Kinyuru et al., 2013). Therefore,

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### Table 2. Iron and zinc contents (mg/100 g dry matter) of four species of termites consumed in Kenya.

<table>
<thead>
<tr>
<th>Termite</th>
<th>Iron (mg/100 g)</th>
<th>Zinc (mg/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. subylanus; dewinged</td>
<td>53.33 ± 1.46</td>
<td>8.10 ± 2.80</td>
</tr>
<tr>
<td>P. militaris; dewinged</td>
<td>60.29 ± 1.11</td>
<td>12.86 ± 0.92</td>
</tr>
<tr>
<td>M. bellicosus; dewinged</td>
<td>115.97 ± 3.46</td>
<td>10.76 ± 1.93</td>
</tr>
<tr>
<td>P. spiniger; dewinged</td>
<td>64.77 ± 2.66</td>
<td>7.10 ± 1.82</td>
</tr>
</tbody>
</table>

1Source: Kinyuru et al., 2013.

4 Examples of omega-3 fatty acids and omega-6 fatty acids are α-linolenic acid and linoleic acid, respectively (van Huis et al., 2013).

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### Table 3. Fat content of some insect species consumed in Africa.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Fat content (% of dry weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>African palm weevil</td>
<td><em>Rhyynchophorus phoenicis</em></td>
<td>54</td>
</tr>
<tr>
<td>Edible grasshopper</td>
<td><em>Ruspolia differens</em></td>
<td>67</td>
</tr>
<tr>
<td>Variegated grasshopper</td>
<td><em>Zonocerus variegates</em></td>
<td>9</td>
</tr>
<tr>
<td>Termites</td>
<td><em>Macrotermes sp.</em></td>
<td>49</td>
</tr>
<tr>
<td>Saturniid caterpillar</td>
<td><em>Imbrasia sp.</em></td>
<td>24</td>
</tr>
</tbody>
</table>

1Source: Van Huis et al., 2013.
edible insects can be used as an alternative to supply these essential fatty acids to local diets with limited access to fish. However, insect food products are susceptible to rapid oxidation of unsaturated fatty acids, leading these products to become rancid quickly. This needs to be checked, especially during processing, to ensure high quality of the final product (Kinyuru et al., 2010).

**Fiber**

Insects have been found to contain significant amounts of fiber with the most common form being chitin, derived from the exoskeleton and accounting for approximately 10% of the dried weight (Belluco et al., 2013; van Huis et al., 2013). Chitin is believed to be indigestible by humans, but different studies have discovered active chitinase in human gastric juices, especially in tropical countries where entomophagy is common (Belluco et al., 2013). The properties of the polysaccharide have been associated to that of dietary fiber. Thus, edible insects, especially those with a hard exoskeleton, are a suitable source of fiber.

**Conclusion**

Edible insects are found in a wide variety of species and are an important food item, which has a high nutritive value suitable for human nutrition. Insects are a suitable alternative food source, which can aid in the management of nutrient deficiency and overall food security if used on a wide scale. However, the commercialization of insects has to be managed efficiently through their rearing as mini-livestock and improved conservation to ensure their wild populations are not affected.

**Literature Cited**


About the Authors

John N. Kinyuru is a food and nutrition researcher and lecturer in the Department of in Food Science and Technology at the Jomo Kenyatta University of Agriculture and Technology, Kenya. He graduated with a degree in food science and technology; M.Sc. in food science and post-harvest technology; and Ph.D. in development and evaluation of insect-enriched foods for management of malnutrition among young children. He has undergone a wide range of specialized professional training programs in food security, nutrition, climate change, and biodiversity and is responsible for teaching general and advanced courses in food sciences, food technology, and nutritional sciences. His research interests fall broadly within utilization of indigenous knowledge and foods for food and feed. Specifically, he is interested in the exploitation of edible insects in human nutrition and health. He has been involved in funded projects in collaboration with international partners, experts, and local farming communities on edible insects.

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Joseph Birundo Mogendi is a doctor researcher and tutor in the Faculty of Bioscience engineering, Division of Agro-Food Marketing and Chain Management at the University of Ghent, Belgium. He graduated with a bachelor’s degree in food sciences and nutrition (Jomo Kenyatta University of Agriculture and Technology, Kenya), an international master’s degree in nutrition and rural development, specializing in public health nutrition (University of Ghent, Belgium), and is currently finalizing his Ph.D. on healthy value chains as an alternate for preventing nutrition deficiencies in developing countries (University of Ghent, Belgium). From 2009 to 2012, he was a VLIR fellow and thereafter awarded a BoF fellowship for his doctoral research. His current research focuses on novel nutrition interventions and healthy value chains, such as biofortification, in the prevention of micronutrient deficiencies in developing countries. He hopes to contribute more in this line of research through application of innovative approaches to design nutrition interventions targeted to vulnerable groups in Africa and other parts of the developing world. He has published widely on the uptake of different novel strategies geared to increasing the nutritional status of vulnerable groups.

Chris A. Riwa is a research consultant and industrialist with a bias towards the food technology sector. He graduated with a degree in food science and post-harvest technology from the Faculty of Agriculture at the Jomo Kenyatta University of Agriculture and Technology. He has experience in food product development, industrial level production, and processing technologies of a wide range of innovative and nutritious foods including extruded products with edible insects and dehydrated vegetables. He has a passion in innovation and enterprise development spanning from food production through processing and eventually to marketing.

Nancy W. Ndung’u is a financial consultant and agricultural entrepreneur at Sweetam Co. LTD, a company she started in 2011. She graduated with a degree in science (botany and zoology) and an M.Sc. in entrepreneurship. She worked in the banking sector as a portfolio adviser before starting her own company. She is currently involved in insect farming in Kenya, specifically crickets and mealworms and is also a trainer to farmers interested in agricultural-based business. She is partnering with international organizations and researchers to study and promote insect farming.