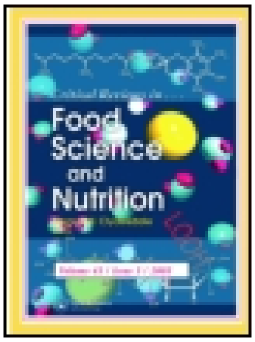

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# Postharvest processes of edible insects in Africa: A review of processing methods, and the implications for nutrition, safety and new products development

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**Postharvest processes of edible insects in Africa: A review of processing methods, and the implications for nutrition, safety and new products development.**

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**Abstract**

In many African cultures, insects are part of the diet of humans and domesticated animals. Compared to conventional food and feed sources, insects have been associated with a low ecological foot print because fewer natural resources are required for their production. To this end, the Food and Agriculture Organization of the United Nations recognized the role that edible insects can play in improving global food and nutrition security; processing technologies, as well as packaging and storage techniques that improve shelf-life were identified as being crucial. However, knowledge of these aspects in light of nutritional value, safety, and functionality is fragmentary and needs to be consolidated. This review attempts to contribute to this effort by evaluating the available evidence on postharvest processes for edible insects in Africa, with the aim of identifying areas that need research impetus. It further draws attention to potential postharvest technology options for overcoming hurdles associated with utilization of insects for food and feed. A greater research thrust is needed in processing and this can build on traditional knowledge. The focus should be to establish optimal techniques that improve presentation, quality and safety of products, and open possibilities to diversify use of edible insects for other benefits.

**Key words**

Entomophagy, traditional knowledge, shelf-life, packaging, storage, functionality.



 

**1.0 Introduction**

The 2009 World Summit on Food Security recognized that global food production must increase by 70% to be able to feed a world population of 9 billion people by 2050 (FAO, 2009). Going together with the expected increase in food production, output of high value protein foods that include meat and fish, was projected to double (Van Huis *et al.*, 2013), particularly because of an increase in demand emanating from growing urbanization, and increasing incomes and affluence in developing countries. The demand for high value protein has impact on demand for animal feeds and the overall natural resource base for their production. Protein production from conventional livestock is expensive and is highly environmentally impacting (Pimentel and Pimentel, 2003; Steinfeld *et al.*, 2006). It was estimated that if the impeding demand for protein was met through livestock production, greenhouse gas emissions would increase by 39%, reactive nitrogen mobilization (global nitrogen misallocation) by 36%, and biomass appropriation by 21%, by 2050 relative to levels reported in the year 2000 (Pelletier and Tyedmers, 2010). Such trends will exacerbate environmental pollution attributable to livestock production. Steinfeld *et al.* (2006) estimated that livestock production consumes 30% of crops, 8% of water resources, and produces 18% of the total greenhouse gas emissions. Even so, the supply of common ingredients for feed manufacture such as fish meal, bone meal, blood meal and plant protein sources including soybean, sunflower, and cotton seedcake, is threatened by competing uses as food for humans, diminishing farm land, over-exploitation of sources, and climate change effects. The impact has been a steady rise in prices for high quality animal protein (Tran *et al.*, 2015; Van Huis, 2013).

Greater use of alternative protein sources such as those of plant origin has been suggested. Plant protein sources are linked with bioactive compounds that can help promote good health (Friedman, 1996) but some limitations include anti-nutritional factors, amino acid imbalances, and high contents of fiber and non-starch polysaccharides depending on the specific sources. Use of insects is another alternative. Insects are able to convert ingested organic matter into high quality protein and other nutrients more efficiently than conventional vertebrate livestock, and are therefore associated with a small ecological foot print (Gahukar, 2011; Nakagaki and Defoliart, 1991). Oonincx *et al.* (2010) demonstrated that insects produce lower levels of greenhouse gases, such as methane, carbon dioxide, and nitrous oxide, than do cattle, suggesting that they would be a more environmentally friendly alternative to the production of animal protein with respect to these emissions. The rich nutritional composition of insects is well reported in the literature (Nowak *et al.*, 2016; Rumpold and Schlüter, 2013a). Insects are rich in protein and fat with good amino acid and fatty acid profiles, respectively, and high contents of a variety of micronutrients including vitamins, minerals and useful bio-active substances (Musundire *et al.*, 2014a, b). The proteins are of high quality as determined by their high essential amino acid score (46 – 96%) and high digestibility that can exceed 90% (Ramos-Elorduy *et al.*, 1997). The fat content can reach 77% of dry weight, and the fatty acids are generally comparable to those of poultry and fish in their degree of unsaturation, but contain more polyunsaturated fatty acids (PUFAs) such as the essential linolenic and linoleic acids (DeFoliart, 1991). The abundance and quality of these nutrients is, however, variable depending on the insect species, developmental stage, feed substrates, and the geographical origin or habitat (Rumpold and Schlüter, 2013a, b).



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Among various communities in Africa, edible insects are harvested seasonally from the wild at different morphological stages and used for food and feed (Kelemu *et al.*, 2015; Kenis *et al.*, 2014; Van Huis, 2003). This practice, can contribute to greater food and nutritional impacts if supported with the appropriate postharvest technologies that ensure constant supply of acceptable, safe and nutritious products. Thus postharvest represents an important technology readiness level for overcoming seasonality, improving food and feed value, and widening the utilization options. The term postharvest envisages a system of interconnected activities from the time of harvesting up to the time a decision to use the product is made; it is characterized by operations that include selection of raw material source, cleaning, processing, packaging, handling and storage. Understanding how different procedures that characterize these operations would affect physical material losses, nutrient content and bioavailability, as well as product safety and acceptability can offer crucial guidance to technological improvements. The objective of this review was to consolidate available evidence of postharvest technologies for edible insects in light of the fundamental considerations for effective processing, packaging and storage, and therefore help to identify areas that need more research attention to generate knowledge that would feed into technology improvements in Africa.



## *2.0 Diversity and importance of edible insects as nutrient source in Africa*

### *2.1 Insects as human food*

Insects have nutritional and economic significance in many African cultures. A wide range of insect species are collected in the wild and eaten, or used to feed animals. DeFoliart (1999) reported that some 209 insect species are eaten either as delicacies or as components of the daily diets. A bigger number was reported by Van Huis (2003), who identified 246 edible insect

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species belonging mainly to the orders Lepidoptera (30%), Orthoptera (29%), Coleoptera (19%) and other orders (22%) including, Isoptera, Homoptera, Hymenoptera, Heteroptera, Diptera and Odonota. However, without considering the scientific identities, Ramos-Elorduy *et al.* (1997) declared a total of 524 insect species as being edible in 34 African countries, with Central Africa Republic (185 species), Democratic Republic of Congo (DRC) (51 species) and Zambia (33 species) being the main countries where insects were eaten. In a recent survey, Kelemu *et al.* (2015) reported the existence of over 470 species of edible insects with highest diversity in the orders Lepidoptera, Orthoptera and Coleoptera. The Central African region alone was reported to host about 256 edible species followed by southern Africa (164 species), eastern Africa (100 species), western Africa (91 species) and northern Africa (8 species). According to DeFoliart (2005) over 182 species of insects belonging to 5--7 orders are edible in Congo (30), Madagascar (22), South Africa (36), Zaire (62), and Zimbabwe (32). In Nigeria, Alamu *et al*. (2013) reported 22 edible insect species of the orders Lepidoptera, Coleoptera, Orthoptera, Isoptera, Hemiptera and Hymenoptera. Among the Mbunda people of Angola, Zambia and Namibia, about 31 species of insects were reported to be edible (Silow, 1983), whereas among the Ngandu people of the DRC, 21 insect species were consumed (Takeda and Sato, 1993). In Botswana, Obopile and Seeletso (2013) identified 27 edible insects. In Kenya, the 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.*, 2010).

The importance of insects in the nutrition of specific communities in Africa is highlighted in a number of studies. In Uganda, grasshoppers contribute about 16,100 Kcal and 513 g of protein per person per annum (Mbabazi, 2011). Intensive studies conducted among the Bemba people of north-eastern Zambia and neighboring areas of the DRC and Zimbabwe, listed 38 different species of caterpillars. Malaisse (1997) pointed that 40% of the total animal protein consumed in the DRC came from caterpillars alone. According to Kitsa (1989) and Vantomme *et al.* (2004), the average household in Kinshasa, DRC, ate approximately 300 g of caterpillars per week translating into 96 metric tons, the quantity of caterpillars consumed in the city annually. Among the Gbaya people of Central African Republic insect consumption was reported to account for 15% of the protein intake. Moreover, 95% of forest people in the Central Africa Republic were reported to depend on insects to meet their protein needs (Vantomme *et al*, 2004), with insects sometimes being the only source of essential proteins (amino acids), fats, vitamins and minerals (Van Huis, 2013). In central Africa, insects are widely available in village markets and some of the favorite species also reach urban markets and restaurants (Vantomme *et al*, 2004). Thus, in some communities, insect consumption is regarded as filling the protein gaps in the largely vegetarian diets and even though the quantities consumed may be small annually, they are significant on a seasonal basis, particularly in months of food shortage prior to harvests (DeFoliart, 1999). In Malawi, caterpillars are available from mid – October to December when food stocks are declining, whilst in Zambia caterpillars are the single most important source of nutrients during the low food supply season spanning November – February, and constitute 40% of the specialties consumed by the Lala tribe during this period (DeFoliart, 1999). In Zimbabwe, the consumption of insects was reported to contribute significantly in the prevention of protein malnutrition and Kwashiorkor among poor rural communities (DeFoliart, 1999), and recently, Dube *et al.* (2013) found that the non-insect eating population comprised less than 10% countrywide. Furthermore, the sale of edible insects is an important income source in Zimbabwe

(DeFoliart, 1999; Kozanayi and Frost, 2002), Uganda (Agea *et al.*, 2008), Malawi (Munthali and Mughogho, 1992), Nigeria (Agbidye *et al.*, 2009) and in Zambia, Botswana and South Africa, where significant levels of inter-country trade involving mopane caterpillar across these countries is reported (Baiyegunhi *et al.*, 2016; Madibela *et al.*, 2007). In the Sahelian region the sale of harvested and marketed grasshoppers and locusts may yield more revenue for farmers than millet (Van Huis, 2003). In South Africa, Styles (1994) and Ghazoul (2006) estimated annual sales of mopane worm to worth US$ 85 million and employ over 30,000 people in each season. According to Zitzmann (1999) income from selling of *Imbrasia belina* in Botswana was estimated to represent 13% of the total household annual income.

*2.2 Insects as feed for animals*

Many insect species are part of the natural diet for fish and poultry in the wild or under traditional free range scavenging systems. Chicken under free range rearing systems scavenge for insects from the wild, and farmers often trap or harvest insects for their poultry while maggots and termites are used as bait in fishing (Farina et al., 1991; Okedi, 1992; Ekoue and Hadzi 2000). In Africa, use of insects to feed animals has been documented in Angola, Benin, Burkina Faso, Nigeria, Togo, Cameroon, Democratic Republic of Congo (DRC) and South Africa (Ekoue and Hadzi, 2000; Farina *et al.*, 1991; Iroko, 1982; Mushambanyi and Balezi, 2002; Téguia *et al.*, 2002). Considerable research on the suitability of insects including termites, housefly, black soldier fly, grasshoppers, locusts and crickets as ingredients in poultry, fish and pig feed formulations in Africa is also documented (Kenis *et al.*, 2014; Moreki *et al.*, 2012; Makkar *et al.*, 2014).

**Insects as feed for poultry**

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In Togo, termites are trapped using calabashes filled with fibrous humidified waste and fed directly to guinea fowls and chicken (Farina *et al.*, 1991). In South-Western parts of Burkina Faso over 70% of the farmers in rural villages use termites to feed poultry where it was reported that substitution of the fish meal in chick diets with fresh termites of the genus *Macrotermes* gave higher feed conversion ratio (Kenis *et al.*, 2014). In Uganda, about 5% of fish farmers use termites as supplementary feed (Rutaisire, 2007), whereas in Southern Africa, mopane moth (*Imbrasia belina*) caterpillar, and cockroaches (*Blatta orientalis*) were tested and used successfully for poultry feed (Moreki *et al.*, 2012; Mushambanyi and Balezi, 2002). In the Democratic Republic of Congo, feeding chicks on feed containing 12% termite (*Kalotermes flavicollis*) gave good weight gain, and was found to be more profitable than conventional feed containing meat meal (Mushambanyi and Balezi, 2002). In Nigeria, meals of black soldier fly (*Hermetia illucens)* larvae, *Cirina forda* larvae, the silkworm *(Anaphe infracta*) caterpillar and grasshopper were used in broiler rations without adversely effecting weight gain, feed intake or growth rate (Ijaiya and Eko, 2009; Ojewola et al., 2005; Oluokun, 2000; Oyegoke *et al.*, 2006) With respect to layers, fish meal could be replaced up to 75% with *C. forda* larvae meal but higher levels resulted in lower feed intake, weight gain, egg production, feed efficiency and egg quality (Amao *et al.*, 2010). Other findings revealed that replacement of conventional fish meal with maggot meal in chick feed was ideal but proportions of the maggot meal exceeding 33% lowered feed intake and growth (Atteh and Ologbenla, 1993). The decrease in feed intake was attributed to feed darkening which is possibly the result of oxidative deterioration causing lower palatability.

**Insects as feed for fish**

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A number of works evaluated the suitability of insects in fish diets, mainly in West Africa. Hem *et al.* (2008) tested the use of *H. illucens* larvae for tilapia in Guinea and obtained satisfactory growth rate when a diet comprising 30% *H. illucens* and 70% rice bran was provided In Nigeria, the work of Sogbesan and Ugwumba, (2008), determined that dried termite (*M. subhyalinus*) meal fed on catfish fingerlings gave best growth rate and cost-benefit ratio when the termite meal and fish meal were combined in a 1:1 ratio. The desert locust meal (*Schistocerca gregaria*) was found suitable for replacing up to 25% dietary protein in African catfish (*Clarius gariepinus*) juveniles without causing significant reduction in growth (Balogun, 2011). Migratory locust meal (*Locusta migratoria*) could also replace fish meal up to 25% in diets of Nile tilapia fingerlings without adversely affecting nutrient digestibility, growth performance, and hematological parameters (Abanikannda, 2012; Emehinaiye, 2012). It was, however, postulated that high levels of chitin present in *S. gregaria* could contribute to reduced performance when higher substitution rates were used. Similarly, adult variegated grasshopper (*Zonocerus variegatus*) meal was also shown to replace up to 25% fish meal in the diets of *C. gariepinus* fingerlings without any adverse effect on growth and nutrient utilization while greater inclusion rates decreased digestibility and performance possibly due to the lower protein value and higher level of crude fiber in grasshopper meal (Alegbeleye *et al.*, 2012; Nnaji and Okoye, 2005). It was also shown that Nile tilapia fed a 4:1 mixture of wheat bran and live housefly (*Musca domesticus*) maggots had better growth performance, specific growth rate, feed conversion ratio, and survival than fish fed wheat bran alone (Ebenso and Udo, 2003). When maggot meal was included in the diet to replace fish meal, best performance and survival were obtained with 34% substitution without causing any adverse effects related to hematology and homeostasis.




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According to Fasakin *et al.* (2003), catfish (*Clarias gariepinus*) fingerlings performed better when fed diets containing defatted maggot meals than full-fat maggot meal owing to the higher nutrient density. Elsewhere, Kroeckel *et al.* (2012) showed that inclusion of black soldier fly pre-pupae meal in the diet of turbot (*Psetta maxima*) juveniles resulted in lower specific growth rate, and inclusion rates exceeding 33% decreased acceptance of the diet. The authors postulated that chitin might have influence on feed intake and digestibility of nutrients, and therefore growth performance (Kroeckel *et al.*, 2012). The influence of feeding whole or size-reduced insect material was also reported. Bondari and Sheppard (1987) determined that feeding chopped black soldier larvae resulted in better weight gain and feed consumption when used as catfish (*Ictalurus punctatus*) feed, but at the same time, lower feed efficiency as a result of greater wastage was observed. However, when fed to Tilapia (*Oreochromis aureus*), the chopped larvae improved weight gain by 140% and feed efficiency by 28% as compared to the whole larvae which did not provide sufficient dry matter or protein intake for good growth.

**Insects as feed for pigs**

Trials in Nigeria (Adeniji, 2008) demonstrated that weaned piglets could be fed 10% rumen content-maggot meal mixture (rumen content and maggot meal mixed at a ratio of 3:1 w/w) without any adverse effects. Early work in Kenya by Hemsted (1947) investigated the use of sun-dried red locust meal as a protein source for pigs at a 20% total protein content mix, and reported satisfactory growth rate although the pork and bacon had a definite fishy taint which decreased upon withdrawal of the locust meal from the diet three weeks prior to slaughter.

These studies show that insects can replace the main dietary protein sources (fish meal, meat meal, soya meal, or groundnut cake) in animal feeds by 25–75%. Specific suitability issues arise depending on the type of insect, type, age and purpose of consuming animal, and amount fed. Processing can help to improve the suitability. There exists therefore, need to determine appropriate processing methods as well as optimal incorporation rates of different insect species in typical feed formulations for various animal categories.

*2. 3 Traditional processing of insects in Africa*

Table 1 shows the various methods used for processing different kinds of insects for consumption by humans. In all cases, the insects are harvested from the wild. As a first step, the extraneous matter and unpalatable parts are separated by removing the gut, wings, legs and head depending on the species and washing in cold or tepid water. The insects are then roasted or boiled, and eaten whole, or processed into powder after sun-drying. In some instances, the insects are eaten raw. The mopane caterpillars and ground crickets that are favorably eaten in the southern parts of Africa are degutted, washed boiled in salty water or roasted, and then sun-dried or smoked and packed in sacks for storage or large tins and plastic containers for sale to traders and consumers, respectively (Kozanayi and Frost 2002; Kwiri *et al.*, 2014; Musundire *et al.*, 2014b). In Sudan, the Sorghum bag (*Agonoscelis versicolor*) is roasted and the oil occasionally extracted for use in food preparation (Van Huis, 2003). In Kenya, termites are de-winged, toasted and then sun-dried (Kinyuru *et al.*, 2009), whereas in Uganda they are steamed in banana leaves or fried and pounded into a cake (Van Huis, 2003). In the Sahel, DRC, Sudan and Uganda, the locust and grasshopper are fried after removing the antennae, legs and wings (Van Huis, 2003). In some parts of Sudan, the head and the abdomen are also removed such that only the thorax is eaten (Van Huis, 2003). In Botswana, the San of central Kalahari harvest a variety of insects (locusts, grasshoppers, hawk moth, (*Herse Convovuli*), buprestid beetle (*Sternocera Orissa*), harvester termite, (*Hodotermes mossambicus*) which they prepare by roasting in hot ash or sand after removing the heads, wings and the internal organs (Nonaka, 1996). In Zimbabwe and Northern parts of South Africa, the stinkbugs (*Encosternum delegorguei*) are eaten either raw or cooked; in most cases, heads are removed and sometimes the fried insects are sun-dried for storage (Musundire *et al.*, 2016a). Thus the elemental operations for processing insects for human food in Africa involve cleaning followed by dry- or wet-thermal treatments, and these may be accompanied by drying and grinding before packaging and storage.

In Table 2, the various methods of processing and incorporating insects in feeds are summarized as extracted from animal feeding studies conducted in Africa. The elemental processes include cleaning (sieving or washing several times in cold or warm water), heat processing (blanching, boiling or roasting), drying (sun-drying or oven-drying) and then chopping or grinding into a granular meal or paste. The meal is constituted into feed by mixing with other ingredients to form a mash. in some cases the mash is moistened and extruded into pellets using simple equipment (Ali *et al.*, 2015; Aniebo *et al.*, 2009; Fasakin *et al.*, 2003; Idowu and Afolayan, 2013; Ogunji *et al.*, 2008; Salau, 2013; Sogbesan *et al.*, 2006; Sogbesan and Ugwumba, 2008).



**3.0 Effect of processing on nutritional value and functional properties**

*3.1 Effects on nutritional value*

A number of studies evaluated the effects of processing on nutritional value of edible insects in Africa.

**Degutting**

Degutted mopane caterpillars contained higher levels of crude protein, acid detergent fiber and *in vitro* true dry matter digestibility. However, they contained lower levels of ash, acid detergent lignin and condensed tannins (Madibela et al. 2009). The observations were attributed to the effects of leaves from Mopane vegetation, which diluted levels of crude protein, acid detergent insoluble nitrogen, Zn and Mn but increased the levels of ash, fiber, condensed tannins, as well as Ca and P in the un-degutted worms.

**Boiling/ frying / toasting/ smoking /roasting**

Boiling decreased the contents of ash, crude protein, and acid detergent insoluble nitrogen, and *in vitro* true dry matter digestibility of mopane caterpillar (Madibela *et al.*, 2007). Boiled or fried and dried Sudanese tree locusts (*Anacridium melanorhodon*) collected from local markets in Khartoum exhibited low protein digestibility (El Hassan *et al.*, 2008); the fried form exhibited lower digestibility (41%) compared to the boiled ones (50%). The fried Sudanese tree locusts contained higher levels of K and lower levels of P, whereas the levels of Ca, Na, Fe, Mg, Zn and Co in the boiled or fried products did not differ. However, percent extractabilities (potential bioavailability) of Ca, K, Fe, Zn, and Co were higher in the fried locusts while extractabilities of Na and Mg were higher in the boiled ones (El Hassan *et al.*, 2008). Boiling of *Hemijana variegat*a caterpillars as traditionally practiced in South Africa lowered the energy value and protein content by 44% and 15%, respectively (Egan et al., 2014). Elsewhere, frying of *Rhynchophorus phoenicis* and *Oryctes monoceros* (Edijala *et al.*, 2009) increased lipid contents by 6% and 10%, respectively, and also increased the cholesterol levels by 3 – 10%. Toasting of

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edible termites and grasshoppers was found to decrease *in-vitro* protein digestibility by ~3% (Kinyuru *et al.*, 2010), and caused significant loss of vitamins including riboflavin (23-34%), niacin (7-21%), pyridoxine (4-6%), retinol, ascorbic acid (16-25%), folic acid (37-43%) and *α*-tocopherol (6-20%). Toasting also decreased fat content by ~ 8% on dry matter basis. Smoking decreased lipid and cholesterol contents of *R. phoenicis* and *O. monoceros* significantly (Edijala *et al.*, 2009). Smoking of *R. phoenicis* and *O. monoceros* decreased lipid levels by 9% and 19% while the cholesterol contents decreased by 41% (from 500.9 mg/100g), and 80% (from 223.5 mg/100g), respectively. Roasting increased the contents of minerals, neutral detergent fiber, acid detergent fiber, acid detergent lignin, and available crude protein of mopane caterpillars (Madibela *et al.*, 2007), but decreased acid detergent insoluble nitrogen and *in vitro* true dry matter digestibility.

**Drying**

Relative to freeze drying, oven-drying (66 °C; 24h) was found to double the concentration of essential and non-essential amino acids in *Sternocera orissa* (Shadung *et al.* 2012) possibly because of hydrolytic and chemical inter-conversions. Oven-drying also increased minerals concentration (Shadung *et al.* 2012). Prolonged oven-drying of *H. variegat*a caterpillars (from 24 h to 72 h) was, however, found to decrease the energy value by 9%;but without affecting the proximate composition Egan *et al.* (2014). On the contrary, Fasakin *et al.*, (2003) reported higher energy values for sun-dried maggot meal as compared to oven-dried meal, but slightly higher protein content in the oven-dried one. The work of (Aniebo and Owen, 2010) found that oven-dried maggots contained higher protein content (50.9%) and less fat (22.8%) than sun-dried ones

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(47% protein and 26.4% fat). Solar-drying of grasshoppers and termites resulted in significant loss of riboflavin (29-46% loss), folic acid (47-66%), niacin (6-26%), pyridoxine (9-13%), retinol (30-56%), ascorbic acid (25-55%), and *α*- tocopherol (9-30%) (Kinyuru *et al*., 2010). Solar-drying of fresh or toasted grasshoppers also decreased *in-vitro* protein digestibility by ~2-5% but this effect did not occur on termites (Kinyuru *et al.*, 2010).

Many factors influence nutritive changes during processing. From cited examples methods used also result in considerable loss of nutrients, nutrient digestibility, and bioavailability. Protein digestibility is decreased by the formation of disulfide linkages within the protein matrix. Digestibility may, however, increase if unfolding of polypeptide chains is promoted (Opstvedt *et al.*, 2003). These events depend on the intrinsic forces contributing to conformational stability of the proteins of different sources. Low protein digestibility is also associated with anti-nutritional factors such as enzyme inhibitors or the formation of stable complexes. Interactions with phytates and polyphenolic compounds such as tannins make proteins unavailable to digestive enzymes. Autoxidation reactions (which proceed at higher cooking temperatures) significantly facilitate formation of covalent bonds that irreversibly link polyphenols with proteins hence lowering protein digestibility (Veldkamp et al., 2012). Increase in fiber content or loss of available lysine during processing are other reasons for a decrease in protein digestibility (Oria *et al.*, 1995). The loss of vitamin content is linked to dehydration, oxidation, and enzymatic or chemical degradation, especially in the presence of transition metal elements such as Cu and Fe (Negi and Roy, 2001). Thus processes that allow contamination by transition metal ions e.g. from equipment or process water, could cause significant losses due to catalytic effects of these elements. The rate of the vitamin destruction is accelerated by heat. Some other vitamins undergo geometric isomerization upon thermal treatment (e.g. vitamin A) thereby losing the vitamin value. Furthermore, water soluble vitamins as well as other beneficial bioactive compounds can be lost through leaching effects in wet heat-treatments such as boiling (Gokoglu *et al.*, 2004; Musundire *et al*., 2014a; Musundire *et al.*, 2016b). In frying, fat content in fried products increases due to absorption (Gokoglu *et al.*, 2004).

*3.2 Effects on functional properties*

Techno-functional properties connote the physical or chemical characteristics of a food or feed ingredient (apart from nutritional value) that affect its utilization (Kinsella, 1976). Edible insects are promoted primarily for their protein content. The effects of some processing and preservation methods on important functional properties of edible insect flours were reported.

**Water absorption**

The degree of water absorption is an important performance indicator in the formulation of various foods; high water absorption is specifically desirable for formulations requiring a high viscosity such as baked products. Sudanese tree locust flour derived from fried locusts exhibited lower water absorption capacity (by a margin of 16%) than similar flour derived from boiled locusts (El Hassan *et al.* 2008)**.** The flour of boiled and sun-dried *C. forda* larvae specimens sampled from local open air markets in Nigeria possessed good water absorption capacity (248g/100g) (Osasona and Olaofe 2010). However, Omotoso (2006) observed higher water absorption capacity (300g/100g) for freshly harvested boiled, oven-dried (40°C) and milled *C. forda* suggesting probable effects of the processing methods or storage**.** Roasting and grilling decreased water absorption capacity of *R. phoenicis* whereas boiling and smoking did not affect this property (Womeni *et al.* 2012). Grilling and roasting caused enhanced the aggregation or crosslinking of proteins which could mask polar groups hence reducing hydration capacity. Thus grilled and roasted insects may not be suitable for formulation of products requiring high viscosity. Different methods of drying *R. phoenicis* (sun-drying, electric drying, smoking) resulted in products with disparate water absorption characteristics (Womeni *et al.* 2012). Poor water absorption of dried products is an indicator of cellular and structural disintegration. Electric drying as well as sun-drying preceded by boiling decreased the water absorption capacity. Dehydration of meat causes hardening of texture and reduction on the ability to absorb water during rehydration as the residual water causes the formation of disulfide bridges and hydrogen bonds between proteins that adhere strongly to each other. The preservation of processed *R. phoenicis* under frozen conditions decreased water absorption because of protein reconfiguration or aggregation. Moreover, cell disruption by ice crystals during frozen storage has some effect in that fatty acids are released which lessens the hydrophilic character of proteins (Womeni *et al.* 2012).

**Water holding capacity**

This property is a useful indicator of the performance in formulations involving dough handling such as baking and extrusion. It is affected by size and shape of protein, steric factors, hydrophilic-hydrophobic balance of amino acids as well as the lipid and carbohydrates composition. Generally, boiling and frying were found to lower the water holding capacity of Sudanese tree locust flours (El Hassan *et al.* 2008), possibly due to matrix contraction and



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denaturation or unfolding of proteins during heating which exposes hydrophobic groups (Abbey and Ibeh, 1987).

**Oil absorption capacity**

Hydrophobic interaction capacity of molecules determines the oil absorption capacity which is a desirable property in flavor retention and improved palatability and mouth feel (Kinsella, 1976). Sudanese tree locust flour processed by milling fried and dried specimens exhibited higher fat absorption capacity than flour processed from boiled and dried specimens (El Hassan *et al*. 2008)**.** Flour processed from boiled and sun-dried *C. forda* larvae collected from local market in Nigeria had low oil absorption capacity of 178g/100g (Osasona and Olaofe 2010). Higher values (358g/100g) were reported for similar flour processed from freshly harvested boiled, oven-dried (40°C) and milled *C. forda* (Omotoso 2006). The work of Womeni et al., (2012) noted that except for boiling, cooking procedures including grilling, roasting and smoking significantly decreased the oil absorption capacity of *R. phoenicis*. These declines could be due to distortion of the native structure of proteins and formation of cross-linkages and aggregates. Dehydration treatments as well as cold storage also lowered the oil absorption of *R. phoenicis* flours by 15--30%.

**Dispersibility/ emulsifying/ foaming properties**

Dispersibility is desirable for enhanced emulsifying and foaming properties of proteins in dough-like formulations (Kinsella, 1976). These properties depend on nature of the protein and process conditions. High emulsion stability and emulsion capacity suggests good functionality as a texturizing agent in food products. Flours produced from fried or boiled Sudanese tree locust**s**



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showed higher dispersibility in neutral compared to acidic (pH 3) and alkaline (pH 10) environments. Moreover, the flours showed similar dispersibilities in acidic and neutral pH, whereas the fried insect flour showed lower dispersibility in alkaline pH (El Hassan *et al.*, 2008). The emulsifying activity, emulsion capacity and foaming capacity as affected by pH were also reported (Babiker *et al.* 2007a). Except for foaming capacity, higher values of these parameters were obtained at alkaline pH for both boiled and fried locust flours. Emulsion stability and foam stability were also higher in alkaline pH range. Flours processed from boiled and sun-dried *C. forda* larvae collected in open-air markets in Nigeria exhibited good emulsion forming capacity (135g/100g) but the foaming ability was poor due to poor dispersibility (Osasona and Olaofe 2010). Better foaming ability was reported for similar flour processed from freshly harvested boiled and oven-dried *C. forda* (Omotoso 2006). Elsewhere, emulsifying activity, emulsifying capacity, emulsion stability, foaming capacity and foam stability of the defatted flours of Sudanese tree locust processed by either boiling or frying in the presence of sodium chloride were reported (Babiker *et al.* 2007b). The fried flour exhibited lower values for these properties in unsalted water. For the boiled locust flour, foam stability was slightly increased, while the emulsifying capacity, emulsifying activity and emulsion stability were slightly decreased as sodium chloride concentration was increased (0 – 1 mol/L). The fried locust flour exhibited increasing emulsifying activity, foaming capacity and foam stability with increasing sodium chloride concentration. Generally, protein functionality was significantly lowered by the process of frying, which would call for use of enhancers such as sodium chloride to improve performance in product systems.

**Solubility**

Protein solubility is a good index of potential applications of proteins (Kinsella 1976). The protein solubility of Sudan tree locust flour as influenced by pH was reported (Babiker *et al.*, 2007a). Flour processed from boiled or fried specimens exhibited higher protein solubility in alkaline medium. Elsewhere, the protein solubility of ground samples of boiled and sun-dried *C. forda* larvae collected from open air market in Nigeria was high in mildly acidic and mildly basic pH, but low at pH 3, 7 and 12 suggesting that *C. forda* flour would be least functional in strongly acidic, strongly basic or neutral processing environments (Osasona and Olaofe 2010). Contrastingly, similar flour produced from freshly harvested *C. forda* (boiled and oven-dried; 40°C) exhibited higher protein solubility in alkaline than in acidic media, with isoelectric points at pH 4, 6 and 9 (Omotoso 2006). Saline conditions also affected protein solubility differently for differently processed insects. Protein solubility of fried locust flour increased markedly with increasing sodium chloride concentration (0 – 1 mol/L); the increase was only marginally for the boiled locust flour.



**Bulk density**

This property is a function of particle size of a granular or powdery product and increases with fineness of particles. A high bulk density is desirable in lowering product paste thickness e.g. in foods for convalescents and children (Womeni *et al*., 2012). The bulk density of fried Sudanese tree locust flour was higher than that of the boiled locusts (El Hassan *et al.* 2008). The finding of Women *et al*., (2012) also showed that boiling, smoking and roasting increased the density of *R. phoenicis* flour while grilling resulted in a product with low bulk density probably because of the high temperature involved which caused much stronger structural contraction. Likewise, dehydration processes increased the bulk density of *R. phoenicis* flours in the order: electric drying < sun-drying < smoke drying. Freezing or refrigeration conferred a higher density in the short term (< 7 days) but lower density with prolonged freezing or refrigeration.

**4.0 Effect of processing on safety**

*4.1 Microbial hazards*

In Botswana, Mpuchane *et al.* (1996) reported proliferation of molds including members of the genera *Aspergillus*, *Penicillium*, *Fusarium*, *Cladosporium* and *Phycomycetes* spp. in sun-dried mopane butterflies (*Imbrasia belina*). Certain species belonging to *Aspergillus*, *Penicillium* and *Fusarium* are mycotoxigenic, and indeed, aflatoxins were detected in the products. In Nigeria, Banjo *et al.* (2005; 2006) studied the microbial populations associated with the gut as well as body surface of the domestic housefly (*M. domestica*) and Rhinoceros beetle *(O. monocerus*) larvae. Pathogens comprising *Staphylococcus aureus*, *Bacillus cereus* and coliforms (*E. coli*, *Pseudomonas aeruginosa*, *Klebsiella aerogenes*, *Aerobacter aerogenes*) were isolated. A study conducted in broiler houses in Algeria, showed that the lesser mealworm (*Alphitobius diaperinus*) harbored high levels of pathogenic bacteria (Agabou and Alloui, 2010). The interiors of these insects were found to harbor Gram-negative bacteria including coliforms and streptococci, while the exterior parts harbored mostly *Staphylococcus* spp., *Micrococcus* spp. and *Salmonella* spp. Other studies (Amadi *et al.* 2005; 2014) reported the bacterial populations associated with the skin and intestinal contents of the *Bunaea acinoe* larvae and *R. phoenicis* adult freshly collected from the wild in Nigeria. Generally, bacterial populations were higher in the gut as compared to the skin, and isolates belonged to genera *Staphylococcus*, *Bacillus*, *Micrococcu*s, *Acinetobacter*, *Klebsiella*, *Pseudomonas*, and *Serratia*. The presence of *S. aureus* and *B. cereus* was significant because of their ability to produce enterotoxins although *S. aureus* may easily be destroyed by cooking. Also in Nigeria, Braide *et al.* (2011) reported high bacterial and fungal populations in processed (degutted, washed, spiced, roasted and sun-dried) *B. acinoe* larvae, and isolated *Pseudomonas* and *Proteus spp*. in addition to the toxigenic *S. aureus*, *B .cereus* and *E. coli*. The findings implied inadequate processing or post-processing contamination. *Pseudomonas* and *proteus* spp. are proteolytic and sometimes lipolytic; they are therefore implicated in food spoilage causing undesirable flavor and loss on nutritional value. Fungal strains including *Aspergillus*, *Penicillium* and *Fusarium* spp. which elaborate mycotoxins were also identified. These bacteria and fungi were also isolated in processed *R. pheonicis* purchased from hawkers in open air markets in southern Nigeria, suggesting poor processing, or poor sanitation and inadequate handling during retailing (Braide *et al.*, 2011). In a separate study, the quality characteristics of *R. phoenicis* collected in the tropical rainforest zone of Nigeria were reported (Opara *et al.*, 2012). *Escherichia coli* and *K. aerogenes* were identified in the freshly harvested, whereas *Staphylococcus* spp. was isolated in heat-processed samples collected from hawkers. The contamination of heat-processed *R. phoenicis* was attributed to insufficient heat processing and unhygienic handling by healthy carriers of *Staphylococcus* spp.

Comparatively, different processing methods were shown to have different decontamination effects. The work of Mujuru *et al.* (2014) in Zimbabwe reported the microbiological quality of *G. belina* processed using different traditional methods: boiling in salted water (5% w/w salt; 30 min) followed by solar drying and boiling in salted water followed by open-pan roasting; drum roasting or hot-ash roasting, all after degutting of the insects. Hot-ash roasting was least effective and retained the highest levels of coliforms, *E.coli* and *S. aureus* whereas these organisms were not detected in the boiled and open-pan roasted samples. Solar-drying of the boiled samples encouraged recontamination by molds. Moreover, use of hand gloves during degutting resulted in a better quality product with respect to *S. aureus* contamination, which revealed the importance of sanitation and hygienic handling during processing.



Elsewhere, a controlled study by Klunder *et al.* (2012) evaluated the microbiological quality of farmed mealworm (*Tenebrio molitor*) and cricket (*Acheta domesticus* and *Brachytrupes* spp.) analyzing them as fresh, boiled, roasted and stored samples. These authors reported the presence of Enterobacteriaceae, ($10^4$-$10^6$ cfu/g) and spore-forming bacteria ($10^2$- $10^4$ cfu/g) in the fresh insects, but boiling for 5 min eliminated the Enterobacteriaceae, and not the spore forming bacteria. The boiled insects were found to store well for > 2 weeks when refrigerated at 5 – 7°C; they stored for < 1 week at room temperature unless they were dried or acidified. It was further demonstrated that roasting alone was not sufficient for eliminating Enterobacteriaceae because heat transfer to the inner tissues was inadequate. For this reason, a short blanching step in hot water prior to roasting was recommended. Another process involving lactic acid fermentation was also found to inactivate Enterobacteriaceae. This process, however, only kept the spore forming bacteria population low. Heat treatment can kill Enterobacteriaceae but spore-forming organisms may require a severe heat treatment process such as canning. Blanching followed by roasting for approximately 10 min was found to lower total microorganisms on whole insects by 5 log cycles, while at the same time, decreasing spore count by 2 log cycles (Klunder *et al.*, 2012). After these treatments, the remaining spores can be contained by appropriate packaging and by recruiting additional modifications such as acidification accompanied by storage at low temperature.

The effectiveness of emerging processing techniques which could apply to industrial-scale decontamination of insects was also described. Rumpold *et al.* (2014) investigated the impact of direct and indirect plasma treatments, high hydrostatic pressure treatment, and thermal treatments on the surface and overall microbial contamination of *T. molitor*. Indirect cold plasma treatment, which consists in the use of ionized gases, was effective for surface decontamination. However, hydrostatic pressure (600 MPa) and thermal treatment (90°C; 15 min in water) were better in inactivating the gut microbiota.

A further postharvest concern relates to methods of storage of the processed products as recontamination may occur quickly especially when the products are stored at ambient temperature as commonly practiced in Africa. The quality deterioration of processed (boiled in salt and sun-dried) mopane caterpillar collected from street vendors in Botswana was analyzed (Mpuchane *et al.* 2000). About 70% of the bacterial isolates associated with the product were proteolytic and 75% were either chitinolytic, lipolytic or both. Spore formers, and mycotoxigenic fungal strains of the genera *Aspergillus*, *Penicillium*, and *Fusarium* were frequently isolated. Insect pests including *Dermestes maculatus, Sitophilus zeamais, Corcyra cephalonica, Tribolium confusum, Tribolium casteneum, Oryzaephilus surinamensis, Bracon hebetor, Anisopteromalus cavandrae, Stathmopoda* species and mites were also found following 5 – 8 month storage duration. The interplay between molds, insects and microorganisms in the causation of physical damage, weight loss, odor development, chemical modification, and mycotoxin contamination hasten the postharvest deterioration of the caterpillars (Mpuchane *et al.*, 2000). In Uganda, the shelf-stability of sautéed ready-to-eat edible grasshopper (*Ruspolia nitidula*) were investigated (Ssepuuya *et al.*, 2016) with respect to different methods of processing, packaging and storage. The postharvest shelf-life of fresh *R. nitidula* is 1--2 days. A preservation process involving sautéing (dry-pan frying), drying, and storage at room temperature in opaque vacuum package or transparent plastic container increased the shelf-life to 12 weeks (Ssepuuya *et al.*, 2016). Chilled and frozen temperature storages of the vacuum or non-vacuum packed product increased the shelf-life of *R. nitidula* from 12 to 22 weeks; the products retained overall acceptability of 6--7 on a 9-point hedonic scale and a total plate count of <4 log cfu/g an acid value of <1 mg KOH/g, a peroxide value of < 21.5 meq $O_2$/kg and a thio-barbituric value of <0.08.

In Nigeria, Awoniyi *et al.* (2004) reported the microbiological quality of maggot meal stored in nylon bags at ambient conditions for 9 months. The bacterial count increased three-fold whereas fungal count increased 18- fold due to rehydration from 7.4% to 23.1% moisture content. Pathogenic and enterotoxigenic bacteria (*Bacillus cereus*, *Corynebacterium pyogenes*, *Micrococcus tetragenus*, *P. aeruginosa*, *S. aureus* and *Streptococcus faecalis*) dominated the bacterial population, whereas the mycotoxigenic fungi *Aspergillus flavus* (aflatoxin) and *Fusarium moniliforme* (fumonisin) were isolated. These observations implied that loss of microbiological quality and even toxin production may be favored by storage in inappropriate containers. In Zimbabwe, Musundire *et al.* (2016a) detected aflatoxin in wild collected stinkbugs stored in recycled grain containers (woven wooden dung smeared baskets and gunny bags) that are traditionally used to package the harvested insects. The findings were linked to cross contamination from the bags.




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On another level, insects serve as subtle vectors or passive hosts of vertebrate pathogens which can cause devastating infections (Rivault *et al.*, 1993; Wales *et al.*, 2010). A number of studies have also shown that insects including lesser mealworm (*Alphitobius diaperinus*), secondary screwworm (*Cochliomyia macellaria*), synanthropic flies [flesh fly (*Sarcophaga carnaria*), house fly (*M. domestica*), fruit fly (*Drosophila melanogaster*), and stable fly (*Stomoxys calcitrans*)], American cockroach, (*Periplaneta Americana*), German cockroach (*Blatella germanica*), Oriental cockroach (*Blatta orientalis*), Pacific beetle cockroach (*Diploptera punctate*), and Speckled feeder cockroach (*Nauphoeta cinerea*) are vectors of foodborne pathogenic bacteria, including *Salmonella* and *E. coli* (Blazar *et al.*, 2011). Some insects also play a role in the dissemination of fungal spores. In a study in rural areas of South Africa, Phoku *et al.* (2016) demonstrated that *M. domestica* was a potential vector for dissemination of fungi including those of the genera *Aspergillus, Fusarium*, *Penicillium*, *Cladosporium*, *Moniliella* and *Mucor*. To this end, insects especially those associated with animal manure are likely to disseminate pathogens among humans, livestock and crops, and therefore strict containment and care in harvesting activities should be an important safety consideration.

*4.2 Parasite hazards*

Some insects are intermediate hosts for parasites of importance to human health (Chai *et al.*, 2009; Graczyk *et al.*, 2005). There are not many studies that investigated parasitic hazards connected to edible insects in Africa. Additional examples, however, can be drawn from outside Africa. In Nigeria, a number of worms and protozoans of public health concern (*Trichuris trichiura*, *Ascaris lumbricoides*, *Enterobius vermicularis*,, Taenia *sp*, *Entamoeba histolytica*) were isolated in cockroaches and houseflies in a study that assessed the vectoral capacity of these insects (Oyeyemi *et al.*, 2016). Similar findings were reported in cockroaches in a separate study conducted in Ethiopia (Kinfu and Erko, 2008). In Indonesia, India, Thailand, Jakarta, and Laos, the flukes *Phaneropsolus bonnei* and *Prosthodendrium molenkampi* have been reported in humans. The metacercariae have been found in the naiad and adult forms of dragonfly and damselfly, which are edible (Belluco *et al.*, 2013). The Plagiorchid family of flukes has also been found in humans, probably originating from insect larvae. Natural human infections of *Plagiorchis harinasutai*, *P. javensis* and *P. philippinensis* were reported in Japan, Korea and Philippines (Belluco *et al.*, 2013). The live cycles of these flukes were found to involve aquatic insects that harbor the metacercariae. The nematode *Gongylonema pulchrum* was also reported in humans in Iran (Molavi *et al.*, 2006). This nematode has beetles and cockroaches as intermediate hosts, and is therefore a possible zoonotic agent which could be transmitted via the consumption of poorly cooked insects.

There are other incidences where insects have been vectors for parasites. Triatomine bugs are carriers of *Trypamasoma cruzi* which causes Chagas disease (American Trypanosomiasis); humans become infected when the bugs contaminate human food items or are accidentally ingested (Pereira *et al.*, 2010). The potential hazard of intestinal myiasis, (a phenomenon that occurs when dipterous fly eggs or larvae are ingested in food and passed out in feces as larvae), was also reported in India (Sehgal *et al.*, 2002) and linked to *M. domestica*. Some other insects associated with myiasis include the drone fly (*Eristalis tenax*), Black soldier fly (*H. illucens*) and black blow fly (*Phormia regina*). Other protozoans such as *E. histolytica* and *Giardia lamblia* have been isolated from cockroaches (Graczyk *et al.*, 2005). Cockroaches frequently feed on human feces, and therefore can disseminate cysts of enteric protozoans in the environment if such feces are contaminated (Pai *et al.*, 2003). A field survey carried out in 11 primary schools in an urban area of Southern Taiwan showed that over 25% of American cockroaches (*P. americana*) and 10% of German cockroaches (*B. germanica*) were positive for infectious of *E. histolytica* and *E. dispar* cysts on the cuticle and in their digestive tracts (Pai *et al.*, 2003). *Isospora* oocysts were also found to reside in dung beetles collected from fecal matter (Saitoh and Itagaki, 1990). Furthermore, a test on the infectivity of *Cryptosporidium parvum* oocysts ingested by dung beetles demonstrated that the oocysts passed unaltered through the mouthparts and gastrointestinal tracts (Mathison and Ditrich, 1999). As reviewed by Graczyk, et al., (2005) synanthropic flies, particularly the common house fly have been identified as vectors of protozoan parasites such as *Sarcocystis* spp., *Toxoplasma gondii*, *Isospora* spp., *Giardia* spp., *Entamoeba coli*, *E. histolytica/ E. dispar*, *Endolimax nana*, *Pentatrichomonas hominis*, *Hammondia* spp., and *C. parvum*.

*4.3 Chemical contamination*

Chemical contamination is a major consideration as insects are often harvested from the wild in Africa. The desert locust, brown locust, red locust and migratory locust are agricultural pests which could be sprayed with insecticides that may still be present at the time the insects are harvested. A few studies reported chemical contamination of edible insects in Africa. The studies show that accumulation in tissues varies depending on species, feed substrates and environment, and level hazardous to humans and animals could be reached. Banjo *et al.* (2010) assessed heavy metal contaminants of edible arthropods collected from markets in south western Nigeria: the African river prawn *(Macrobrachium vollenhovenii)*, brackish river prawn *(Macrobrachium macrocbrachium*), west wood caterpillar *(C. forda*), palm weevil (*R. phoenicis*), African silkworm (*Anaphe* spp), rhinoceros beetle *(Anapleptes trifasciata*), termites (*Macrotermes* spp.), grasshopper (*Z. variegatus*), honey bee (*Apis mellifera*) and crickets (*Brachytypes* spp). The *M. macrobrachium* and *A. trifasciata* were found to contain highest levels of Ni (0.36 mg/kg and 0.34 mg/kg), Cd (0.05 mg/kg and 0.03 mg/kg), and Zn (0.88 mg/kg and 0.79 mg/kg). The level of Pb ranged from (0.03- 0.10 mg/kg). Although the values for each metal did not reach toxic level, the study pointed to a possibility of related risk. Heavy metal contaminations in worker, soldier and primary reproductives of mold termite (*M. bellicosus)* collected from dumpsite, farmland and industrial estate in southwestern Nigeria were reported (Idowu *et al.* (2014). The castes from industrial estate had highest levels of Cu (0.08 mg/kg) whereas those from farmland and the dump site had highest levels of Cr of 0.23 mg/kg and 0.22 mg/kg, respectively. Lead (Pb) was only detected in the soldier castes. The study concluded that termites have a very low tendency to accumulate heavy metals from the soil. In another study, Banjo *et al.* (2012) reported high heavy metal contamination in mealworm larvae and winged termites harvested from the wild. Contaminations by Ca, Zn, and Pb were 11.0 mg/kg, 5.5 mg/kg and 39.6 mg/kg, respectively, in the mealworm larvae, and 12.7 mg/kg, 2.7 mg/kg, and 40.2 mg/kg, respectively, in the termites. The investigators attributed the high contamination levels to wastes released from nearby refinery, airborne residues from mining factories in the neighborhood falling onto the insects' body surfaces, and possibly also, the wrong application of chemical pesticides near the insect habitats. According to European commission's regulation EC/1881/2006, maximum permissible limits of Cd and Pb in animal products range between 0.05 – 1.0 mg/kg and 0.1 – 1.5 mg/kg, respectively (EFSA Scientific Committee, 2015). Greenfield *et al.* (2014) investigated metal concentrations in Mopane worms from the Kruger National Park in the north-eastern region of South Africa (which is home to the African copper belt) and found substantial bioaccumulation. Concentrations of Cd and Cu were 15--26 times and 2--3 times higher than the EU/UK recommended legal limits for human consumption, respectively, whereas zinc levels were tolerable. Manganese concentrations were 20 – 67 times higher than FDA standards. The food eaten by the worms and pollutants settling on leaves were identified as the potential sources of these metals contaminants. Examples from other parts of the world provide further evidence of the possibility of chemical contaminations. High concentrations of residual organophophates (sumithion and malathion) were reported in locusts harvested for consumption in Kuwait (Saeed *et al.*, 1993). Some other studies in Mexico (Cohen *et al.*, 2009) also found that grasshoppers were able to accumulate high levels of Pb. Indeed, an outbreak-related study among children and pregnant women in a community living in Monterey Califonia, linked elevated blood Pb levels to consumption of dried grasshoppers imported from Oaxaca (Handley *et al.*, 2007).

With respect to farmed insects, the quality of feed substrates is important especially when waste side streams are used. Charlton *et al.* (2015) assessed the chemical safety of the larvae of *M. domestica*, *Calliphora vomitoria* (blue bottle fly), *Chrysomya* spp (blow fly) and *H. illucens* reared on a range of waste substrates (brewery solid waste, poultry manure, and pig offal) for animal feed in Mali and Ghana. Chemical contaminants including veterinary residues, pesticides, heavy metals, dioxins and polychlorinated biphenyls, polyaromatic hydrocarbons and mycotoxins in the harvested larvae were determined. Contaminant levels were generally lower than the recommended maximum concentrations suggested by the European Commission, the World Health Organization and Codex Alimentarius Commission. However, high levels of Cd above the recommended limit were found in the *M. domestica* larvae. Elsewhere in Australia, Green *et al.* (2001) demonstrated that *Agrotis infusa* (Bogong moth) was able to accumulate sub-lethal quantities of As, but which could then be bio-concentrated to lethal levels with continued consumption of these moths. In a separate study, yellow mealworm larvae (*T. molitor*) were reported to accumulate Cd and Pb when fed on organic matter collected from soils containing these metals (Vijver *et al.*, 2003). Poultry fed on insects have also been reported to accumulate the heavy metals in their tissues. The investigation of Zhuang *et al.* (2009) on bio-accumulation of heavy metals along the soil-plant-insect-chicken food chain in China, found steady decline in Cd concentration with increasing trophic level and slight increase in the concentrations of Zn and Cu slightly from plant to insect larva. The chicken fed on insect larvae, however, had significantly high levels of Pb, suggesting a bio-accumulation which cannot be ignored.

*4.4 Anti-nutritional factors*

A number of studies investigated the anti-nutritional characteristics of edible insects in Africa. The anti-nutritional factors of wild harvested and dried *O. monoceros* larvae were also reported (Ifie and Emeruwa, 2011). The levels of phytic acid (178mg/100g), tannin (14.3mg/100g) oxalate (2.1mg/100g) were found to be within acceptable levels. The tannin was probably responsible for a low protein digestibility (58%). But with respect to *C. forda* larvae, a widely eaten insect in southern Nigeria, anti-nutritional analysis of degutted, boiled, dried and milled samples collected from the wild revealed low contents of oxalate (4.1mg/100g) and phytic acid (1.0 mg/100g), whereas tannins were not detected (Omotoso, 2006). Elsewhere, in Zimbabwe, high contents of tannins (168 mg/100g) and oxalates (931 mg/100g) as well as high contents of saponins (5330 mg/100g) and alkaloids (5230 mg/100g) in degutted, parboiled, dried and milled ground crickets (*Henicus whellani*) harvested from the wild were determined. Phytates and glycosides were not detected (Musundire *et al.*, 2014b). *Eulepida mashona* beetles (widely consumed in rural farming communities of Zimbabwe) were also found to contain high levels of saponins (19600 mg/100g) and oxalates (2800 mg/100g) in addition to tannins (278mg/100g) and alkaloids (700 mg/100g) on dry matter basis. These compounds were, however, reduced by factors of 12 and 1.4, 1.6 and 2.3 respectively, when the insects were boiled for 30 min. and dried (Musundire *et al*., 2016b). Similar effects were reported for edible stinkbugs, which contained ten times more alkaloids (7400mg/100g) than *E. mashona* (Musundire *et al.*, 2014a). The anti-nutrient factors in processed Sudanese tree locust collected from local market in Sudan were also evaluated by (El Hassan *et al.*, 2008). The fried-dried locust contained higher tannin (9.0 mg/100g) boiled-dried locusts (5.8 mg/100g) probably due to leaching or even complex formation effects in the process of boiling. Contrastingly, phytic acid content was higher in boiled locust flour (350 mg/100g) than in the fried one (293.33 mg/100g).

Tannins form insoluble complexes with protein thereby interfering with their bioavailability. In animals, tannins are associated with decreased feed intake, growth rate, feed efficiency, net metabolizable energy and protein digestibility, whereas phytate and oxalate in the diet of monogastrics, decrease the bioavailability of mineral elements including Ca, Zn, Mn, Fe, and Mg. Phytate is a concern because of the negative effects on growth performance, nutrient metabolism and energy utilization when present in diets of monogastric livestock species such as fish, poultry and pig; phytate levels exceeding 250mg/ 100g dry matter could be detrimental for livestock. For this reason, dephytinization processes for feeds have to be applied to remove or degrade the phytate in the raw materials (Kumar *et al.*, 2012). Saponins, on the other hand, impair the digestion of protein and the uptake of vitamins and minerals in the gut, and can cause hypoglycemia. Alkaloids are known to impart a bitter taste to most foods and some could be toxic to humans and domestic animals at high doses. The anti-nutrient content is a function of the type of insect and diet (Adeduntan, 2005). Thus in mass rearing units, anti-nutritional factors may be overcome by insect selection and manipulation of the diet of insects. Relevant processing can also reduce anti-nutritional factors by extraction and deactivation.

*4.5 Toxicity reactions*

A number of studies demonstrated toxicity in edible insects arising from bioactive compounds synthesized by the insects themselves or substances accumulated from feed substrates. In Burkina Faso, some species of termites (*Cubitermes*) were reported to be toxic to chicks (Kenis *et al.*, 2014). In Benin, feeding trials showed that a humivorous species of the genus *Noditermes* was toxic to chicks and keets (Chrysostome, 1997). Elsewhere, the incorporation of dried bee meal into turkey starter diets at levels of 0 – 30% linearly decreased the performance of the poults, an effect that was linked to the toxicity of bee venom (Salmon and Szabo, 1981). In Côte d'Ivoire, Bouafou *et al.* (2011) showed that maggot meal could eliciting histological and histopathological damages. The study, which compared two groups of young rats fed with two diets containing 10% fish meal or 10% dried maggot meal for 15 d, showed a 6.6% decrease of the weight of the kidneys and 10.6% increase in the weight of the liver of rats fed on maggot meal. Similarly, Akinnawo *et al.*, (2002; 2005) reported neurotoxic effects as well as histopathological changes in the liver, kidney and heart of rats fed on raw *Cirina forda* larvae. The study of Téguia *et al.* (2002) in Cameroon also showed that high proportions of maggot meal in poultry diet increased the mass of liver and gizzard, while the work of Pretorius (2011) in South Africa, which evaluated maggot meal in terms of possible toxicities, organ stress and immune suppression, did not observe the same effects. Elsewhere, in Ghana mass mortality of Guinea fowl keets fed on maggots from decaying animals was reported, although the causal effect was not investigated (Teye and Adam, 2000). In Nigeria, consumption of African silkworm (*Anaphe venata*) was linked to ataxic syndrome and impaired consciousness in humans due to thiamine deficiency caused by the decomposition of dietary thiamine by a heat-resistant thiaminase contained in the caterpillars (Adamolekun, 1993; Nishimune *et al.* 2000).

Some edible insects e.g. Lepidopterans of the genus *Zygaena* accumulate cyanogenic glycosides (Zagrobelny *et al*., 2009), which release toxic hydrogen cyanide upon degradation. In addition to acute toxicity, associations have been made between chronic exposure to cyanogenic glycosides and diseases such as spastic paraplegia, tropical ataxic neuropathy, and goitre. Low levels of cyanogenic glycosides (140 µg/100g) were reported in wild harvested dried and pulverized adult *E. mashona* (Musundire *et al*., 2016b) whereas lower levels (23µg/100g) were reported in stinkbugs (Musundire et al., 2014b). Boiling for 30 min. decreased cyanogen glycosides content of *E. mashona* threefold (Musundire *et al*., 2016b) while, washing and toasting of the stinkbugs as traditionally practiced increased the cyanogen glycoside content threefold (Musundire *et al*., 2014a). The Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2012) has set the provisional maximum tolerable daily intake (PMTDI) for cyanogenic glycosides at 20 µg/kg bw/d. Thus safety concerns of hydrogen cyanide exposure exist where large portions are likely to be consumed especially by children.

Poisonous insects may be categorized as those having phanerotoxic and cryptotoxic effects (Belluco *et al.*, 2013). Phanerotoxic insects such as bees and ants synthesize the poisons in specialized organs, but the toxic substances are inactivated in the digestive tract, thus the danger they pose is during the oral and esophageal passage (Blum, 1994). Cryptotoxic insects release noxious substances resulting from synthesis or accumulation, and the substances may be localized in specific organs or diffused to different body parts (Belluco *et al.*, 2013). Some of the hazardous substances found in insects include metabolic steroids such as testosterone and dihydrotestosterone, found in beetles. As such, the continuous consumption of beetles may lead to growth retardation, hypo fertility, masculinization in females, edema, jaundice, and liver cancer (Blum, 1994). Cyanogenetic compounds may be found in some insects. Blum (1994) reported that cyanogenetic substances may inhibit vital enzymes such as succinate dehydrogenase and carbonic anhydrase, thereby arresting metabolic pathways including oxidative phosphorylation. Another noxious substance, toluene, is found in Longhorn beetles in the *Stenocentrus* and *Syllitus* genera (Blum, 1994). Toluene is a depressant that affects the brain, kidneys and the liver. Some insects such as the *Lytta vescicatoria* contain cantharidine in ovaries and eggs that causes irritation of the bladder and the urethra (Blum, 1994). Benzoquinones have also been reported in Tenebrionidae insects (darkling beetles) that are used in alternative medicine in Argentina. The insects can be cytotoxic, resulting in DNA damage (Brown *et al.*, 1994). Also, many acridids (family of grasshoppers) have their own chemical defenses, often obtained from toxic plants, and eating toxic acridids may be fatal (Steyn, 1962).

Some processing procedures have been shown to lower toxicity of edible insects. For example in Nigeria, Akinnawo *et al.* (2002, 2005) showed that boiling and sun-drying of *C. forda* larvae reduced heart and liver toxicity in albino rats, while thorough heat treatment of *Anaphe venata* pupae was claimed to deactivate thiaminase activity (Nishimune et al. 2000). There remains, however, a need to understand the inherent properties that confer on insects the ability to cause intoxication, the respective tolerance levels, and how processing may help in detoxification.

*4.6 Allergic reactions*

Food allergy refers to the adverse health effects in which immunological mechanisms are involved following dietary exposure to allergens in food (Verhoeckx *et al.*, 2015). Usually it is the result of the body's immune reactions to food proteins. Elaboration of immunoglobulin E (IgE) antibodies is the most common immunological mechanism implicated. However, non-IgE-mediated cellular immune responses are also important in some forms of food allergy. Allergic reactions may be mild such as urticaria or severe such as anaphylaxis, a rapid reaction that can potentially cause death (Verhoeckx *et al.*, 2015). To our knowledge, there is scarcity of information regarding allergenicity of edible insects in Africa, bust some cases have been demonstrated. In Botswana, Okezie *et al.* (2010) reported a case where a 36 year old woman developed two episodes of anaphylactic shocks presenting with itchy skin rash, facial swelling, and mild hypotension after consuming mopane caterpillar, the larval stage of *G. belina* moth. The *G. belina* moth belongs to the Lepidoptera order of insects and some members of this order are known to induce contact allergy. In this case, skin prick test was not conducted. However, in a separate case reported by Kung *et al.* (2011) an atopic adolescent who had ingested mopane caterpillar and developed anaphylactic shock had skin prick test being positive, suggesting a potential for mopane caterpillar to induce allergic reactions. Ingestion of other caterpillars has also been implicated in allergic reactions. In a reported case in Pennsylvania, eight children who had accidentally consumed lepidotera caterpillars developed local and general effects including drooling, difficulty in swallowing and generalized urticaria as a result of spicule envenomation.



 

In these cases, six had consumed caterpillars of the hickory tussock moth (*Lompocampa caryae*) whose body surface is covered with minute spicules (Lee *et al.*, 1999; Pitetti *et al.*, 1999) Mechanical irritation and hypersensitivity reactions to antigens or venom in spicules (setae or caterpillar hairs) may contribute to allergic reaction upon contact. For instance, the protein theumetapoein which can cause mast cell degranulation was isolated in pine processionary caterpillars (*Thaumetopoea pityocampa*). Histamine, trypsin, chymotrypsin, phospholipase and serotonin have been isolated in other species (Lee *et al.*, 1999).

According to Pener (2014) allergic reactions due to consumption of grasshoppers, locusts and crickets can be acute. Piromrat *et al.* (2008) reported seven cases of anaphylaxis caused by fried grasshoppers and crickets during a two-year-period in a hospital emergency department in Thailand. Ji *et al.* (2009) also summarized 27 cases of anaphylactic shock caused by consumption of grasshoppers and 27 cases caused by consumption of locusts in China between 1980 and 2007. Moreover, Lopata *et al.* (2005) reported occupational allergy caused by the African migratory grasshopper (*L. migratoria*) and isolated the potential allergens. The silkworm pupae are, reportedly, allergenic too (Ji *et al.* 2008).

Insect derived products, and insect infested products have also been implicated in allergies (Belluco *et al.*, 2013). Carmine dye, a colorant derived from dried female cochineal insects (mealy bugs, *Dactylopius coccus Costa*/ *Coccus cactus*), and which is widely used as a food colorant in fruit juices, ice cream, yogurt, and candy has been implicated in adverse allergic reactions associated with IgE-induced allergy due to protein residues present in carmine (DiCello *et al.*, 1999). Five people were reported to react upon consumption of alcoholic beverages containing carmine (Wüthrich *et al.*, 1997). In this case, skin prick test and IgE tests specific to carmine were positive. Other cases of allergic reactions including anaphylaxis to cochineal were reported in yoghurt (Beaudouin *et al.*, 1995), Campari-orange drink (Kägi *et al.*, 1994), and carmine-colored Popsicle (Baldwin *et al.*, 1997). Allergic reactions were reported in patients inhaling or ingesting lentils infested with lentil pest *Bruchus lentis* (Armentia *et al.*, 2006). An oral food challenge test demonstrated that *Bruchus lentis* contains proteins that can cause IgE-mediated anaphylaxis and asthma.

Verhoeckx *et al.* (2015) reviewed the impact of processing on the allergenic (IgE binding) and antigenic (IgG binding) integrity, and allergenicity of food proteins from different foods. Earlier, Mills *et al.* (2009) reviewed the impact of food processing on the structural and allergenic properties of food allergens. According to Huby *et al.* (2000) many factors contribute to the overall allergenicity of any given protein among them the function (including enzymatic activity), stability (including resistance to proteolytic digestion), and glycosylation patterns. The food matrix also has impact on allergenic potential by affecting the way the allergens are presented to the immune system (Grimshaw *et al.*, 2003). Thermal processing, fermentation, enzymatic and acid hydrolysis, high pressure processing, irradiation, preservative use, pH alterations, or combinations of these can alter allergenicity of substrates (EFSA Scientific Committee, 2015; Mills *et al.*, 2009; Thomas *et al.*, 2007). Depending on type of protein, thermal processing can cause structural change of allergenic proteins e.g. denaturation of proteins can destroy IgE epitopes or lower their affinity (Verhoeckx *et al.*, 2015). But mild heating may also expose epitopes that were previously hidden thus increase IgE binding (Bu *et al.*, 2009; DeFoliart, 1991). Maillard reactions (reaction between free amino groups on proteins and the aldehyde or ketone groups of sugars during thermal processing) ware reported to lower IgE binding (Bu *et al.*, 2009). Other studies nonetheless showed that glycation by Maillard modifications could increase IgE binding capacity by forming aggregates which bind IgE more effectively or resist gastric digestion (Jiménez-Saiz *et al.*, 2011; Mills *et al.*, 2009). Fermentation seems to strongly reduce allergenicity by causing lower antigenic response and higher IgE inhibition through protein structure alterations induced by low pH and proteolytic action of microbial proteases (Yao *et al.*, 2015). Protein unfolding and aggregation may also be induced by mixing and shearing that occurs during other food processing operations, as well as adsorption processes involved in the stabilization of air–water and oil–water interfaces in food foams and emulsions. Such alterations in protein folding have the potential to affect stability to digestion, and hence the form in which allergens are presented to the immune system (Mills *et al.*, 2009). Other types of processing-induced modification which may affect allergenicity include interactions with oxidized lipids (Shoko *et al.*, 1989) and enzymatic modification with polyphenols catalyzed by the polyphenol oxidase (Mills *et al.*, 2009). The factors associated with allergic reactions still need more research paying attention to the characteristics that confer on insects the ability to induce sensitization, and how these may be influenced by processing.



## 5.0 Prospects for product development

### *5.1 Composite fortified foods*

Edible insects can be utilized to alleviate diet deficiencies among most vulnerable groups if harnessed into human diets. Some studies in this direction were undertaken in Africa. In Kenya, Kinyuru *et al.* (2009) reported the nutritional and sensory qualities of wheat buns enriched with termite flour as protein and micronutrient source. The product derived from 5% substitution of wheat flour with termite meal was acceptable to consumers, and contained significantly higher levels of protein, retinol, riboflavin, iron and zinc. In a separate study, the development of a pre-cooked complementary food (Winfood Classic) based on extrusion cooking of flour composites comprising amaranth grain (71%), maize (10.4%), edible termite (10%), *dagaa* fish (*Rastrineobola argentea*) (3%), soybean oil (0.6%) and sugar (5%) as a nutritious product to combat child malnutrition was reported (Kinyuru *et al.* 2015). Adequate nutrient density and a stable shelf-life of 6 months were reported for this product. Extrusion cooking is a superior processing method because it denatures anti-nutrients. Furthermore, the heat, pressure and mechanical shear generated during extrusion destroy pathogenic bacteria often associated with insects thus improving the safety. Earlier, Konyole *et al.* (2012) tested the acceptability of amaranth and maize grain-based complementary weaning food enriched with *dagaa* fish (3%), and edible termites (10%) among young children and their mothers in western Kenya. The product scored similar acceptability as one not enriched with termite. Ayieko *et al.* (2010) reported "*SOR-mite"* a product comprising sorghum flour blended with termite meal. Also, edible insects including termites and lake flies were roasted, sun-dried, ground and mixed with other ingredients, then processed into food products including crackers, muffins, meatloaf, and sausages and tested at experimental level (Ayieko *et al.*, 2010). In Nigeria, Adepoju and Daboh (2013) and Adeoti *et al.* (2013) produced nutritious composite flour by enriching maize and sorghum flours with *C. forda* larvae powder as source of protein and micronutrients in complementary foods for children, while in Zimbabwe Kwiri *et al.* (2014) reviewed the opportunities for utilizing *G. belina* as protein source in fortified blended foods. Elsewhere outside Africa, the production and characteristics of maize flour tortilla supplemented with *T.*

*molitor* larvae flour was reported in Mexico (Aguilar-Miranda *et al.*, 2002). Tortillas supplemented with 7% the mealworm powder contained higher protein (by 2%) as well as essential amino acids. The product was found to have excellent consumer acceptance, better functional characteristics for taco rolling, exceptional mouth feel sensation, and better taste. These examples show that opportunities exist for new ways to consume insects. Robust processing technologies such as extrusion can be used to enhance attributes, quality and safety of products. Nonetheless, more scientific research is needed to develop the processes for greater product acceptability to drive commercialization.

*5.2 Extraction of insect-base products*

Insect proteins could be used in novel protein supplements (Shockley and Dossey, 2014). Therefore, efforts to produce protein powders and pastes from insects may have potential in high-end protein supplements and beverages. The Mississippi State University Insect Rearing Centre together with Neptune Industries Inc. (USA) developed and patented a production protocol for a dry protein meal, Ento–Protein™ (Veldkamp *et al.*, 2012). The use of insect proteins to supplement conventional food products, however, still requires research around properties of the extracted proteins. These properties include amino acid profile, thermal stability, solubility, gelling, foaming and emulsifying capacities among others (Damodaran, 1997; Shockley and Dossey, 2014). The methods and cost of protein extraction also requires to be explored (Shockley and Dossey, 2014).

The high fat content of some edible insects is valuable in manufacture of foods or industrial products (Li *et al.*, 2011; Mariod, 2013). Fat extraction to produce a de-fatted meal also concentrates the protein. In the Kordofan state of Sudan, oil is extracted from the melon bugs



 

(*Aspongopus vidiuatus*) [40% oil] and sorghum bugs (*Agonoscelis pubescens*) [60% oil] after steeping in hot water. Traditionally, the oils are used in cooking and as medicine for curing skin lesions (Mariod *et al.*, 2004). The potential of these oils for various other uses was reported. The performance of crude oil extracted from sorghum bugs in frying was studied with regard to chemical, physical, and sensory parameters, and was found to be suitable for deep-frying of potatoes for a period of 6 – 12 h (Mariod *et al.*, 2006). Oil extracted from melon bugs was found to have low contents of polyunsaturated fatty acids such as linoleic and linolenic acid, and therefore reported to be useful in improving oxidative stability of other oils such as sunflower oil (Mariod *et al.*, 2005). The insect oils were also tested for biodiesel production. Product characteristics were evaluated according to DIN 51606 specifications for biodiesel, and found to meet most requirements although the kinematic viscosity values were higher, but could be lowered by blending with other low-viscosity biodiesels (Mariod *et al.*, 2006) thereby offering possibility for industrial application. The work of Mustafa *et al.* (2008) further demonstrated high antibacterial activity of melon bug oil against isolates of *S. aureus, Salmonella enterica*, *E. coli*, *B. cereus, B. subtilis, E. faecalis and P. aeruginosa*, highlighting the possibility of using this oil in food preservation. At commercial level, Agriprotein (2015) extracts oil from housefly larvae to produce MagOil™ that is high in unsaturated fatty acids and is a good source for omega 6 fatty acids. The product is sold commercially in the pet food market and to pig farms. In Netherlands, Protix-Biosystems (2015) purifies oils from insects to product that is high in medium-chain fatty acids (lauric acid and linolenic acid), and sold as nutrient for animals such as freshwater fish and chicken.

Gelatin is another product that may be extracted from edible insects. It is derived by the partial hydrolysis of collagen and is widely applied in the food and pharmaceutical industries. Mariod *et al.* (2011) reported extraction of gelatin from dried edible melon bug and sorghum bug in Sudan. The extract was tested in manufacture of ice cream as stabilizing agent. A product containing 0.5% insect gelatin was acceptable and the general preference was not different from ice cream containing commercial gelatin.

Insects can also be a source of chitin (Kaya *et al.*, 2015). The non-toxic biodegradable linear polymer is the main component of insect exoskeleton. Chitin has immune stimulating properties and could improve the immune status of animals if ingested, thus minimizing the use of antibiotics (Koide, 1998). However, too much chitin in a diet is undesirable because of poor digestibility which lowers the nutritional value. Consequently, it may be extracted and channeled into production of high value products. Alternative applications of chitin include use as a nutraceutical to reduce fat or cholesterol (Koide, 1998; Shields *et al.*, 2003), use as a drug carrier or agricultural pest control product, use in water purification and in biodegradable materials as plastic alternatives, use as an antimicrobial ingredient in food and other perishable materials, and use in cosmetics (Tharanathan and Kittur, 2003). By partial deacetylation, partial depolymerization or full depolymerization, chitin can be transformed into chitosan, chito-oligomers and glucosamine with N-acetylglucosamine, respectively. These derivatives have wider applications in food, cosmetic, pharmaceutical, textile, paper and waste water industries (Dutta *et al.*, 2004; Rinaudo, 2006). Currently, commercial sources of chitin are shrimp and crabs that are constantly over exploited. Consequently, insects could be potential alternative sources of chitin and chitosan (Kaya *et al.*, 2015). Protix-Biosystem (Protix-Biosystems 2015) produces chitin-rich powders from insects for sale.

**6.0 Conclusions and recommendations**

The objective of this review was to consolidate available evidence of postharvest technologies for edible insects in Africa, examining them in light of the fundamental considerations for effective processing, packaging and storage. A further aim was to identify areas that need research attention so as to generate knowledge that could feed into technological improvements for enhanced use of insects in human and animal nutrition. Evidently, edible insects are a source of key nutrients in human and animal diets, and generate revenue for communities in Africa. Many species are also fed to animals, and feeding trials show the importance of processing the insects before incorporating into livestock rations. An important revelation is that indigenous processing methods of insects in Africa substantially influence nutritional value and functionality. Processing approaches will need to put focus on determination of optimal conditions and standardization of important parameters for nutritional value retention. Tied to this with regard to animal feeds is the question of practical inclusion levels in diets. Research is needed to generate more knowledge on performance by measuring responses such as feed intake, feed conversion, nutrient utilization, growth rate, and production capacity, as influence by insect ingredients in feeding trials. Furthermore, assessing the quality of products (e.g. eggs, carcass) from the compositional, organoleptic and functional points of view will be essential and should be targeted for research.

It was found that many insect species considered edible in Africa accumulate biological or chemical contaminants that are potentially hazardous and anti-nutritive. This is encouraged by



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natural habitats, feeding behavior, and human activities (e.g. agriculture and mining) close to where insects may be harvested. Insects also serve as vectors or hosts of vertebrate pathogens which can cause devastating infections. The risks might be minimized if the insects are farmed under controlled environments, and public health considerations applied in selection of rearing substrates or when harvesting from the wild. Generally, however, assuring the harvesting of hazards-free insects is difficult; hence postharvest processing remains the only measure for overcoming these safety threats. This review revealed that research and education on effective processing, packaging, handling during retailing, and storage are indeed needed to especially minimize biological hazards. With a few exceptions, majority of insects are utilized whole, together with the gut which is rich in bacteria and parasites. While it is agreeable that some microorganisms and parasites may not present serious safety concerns in thoroughly cooked foods, better knowledge on adequacy of processing methods, in terms of the lethal effects of specific regimes on potential biological hazards is critical. To begin with, the extent to which processes such as smoking, brining, frying, steaming, boiling, roasting, toasting and drying as traditionally practiced, support production of safe products should be established. There could also be benefits when combinations of these treatments are applied. With this knowledge, the necessary improvements should be explored. Moreover, better control of hazards would be achieved if the technologies are standardized and supported by quality assurance mechanisms and testing protocols. Sanitation and safety management tools such as Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Point (HACCP) can improve traditional processing. It is a further research interest to establish what processing techniques are suitable alternatives for industrial or semi-industrial applications. To this end, research should examine improved food and feed science technologies, and how these could be applied within the context of enhancing the indigenous ones. The risks of allergy and toxicity of insects still need more research paying attention to the differences between allergic and toxic responses. There remains a need to understand the inherent properties that confer on insects the ability to induce sensitization or intoxication, and how these may be intercepted through processing.

Another revelation of this review is that proper packaging and storage are challenges that exacerbate quality deterioration, hazard emanation and losses of processed edible insects. With regard to packaging, insects are rich in lipids and protein, thus the packaging needs are similar to those of meat products. The basic purpose should be to offer protection from undesirable impacts on quality including microbiological and physio-chemical alterations, particularly influences affecting color, smell, and taste due to rancidification. Indigenously, processed insects are packaged in tins, plastic containers, baskets or sacks. Improved packaging should to offer good barrier properties against oxygen, water vapor, and light. Packaging in hermetically sealed impermeable films or containers (probably supported by drawing a vacuum), and which are opaque or laminated with aluminum foil will ensure stable quality during storage. With this in the background, research should target identifying cost-effective packaging options. Technologies that can increase shelf-life at ambient temperature should be targeted as they have capacity benefit commercialization in the African context. One such technology is dehydration to the critical water activity level that does not support chemical, biochemical and microbiological deterioration at defined temperature of storage. Dehydrated products, however, rehydrate easily thus knowledge of the hydration dynamics should inform selection of the appropriate packaging.

Processing techniques that improve quality and add value should open new opportunities for use of insects. There are prospects in developing new products such as composite fortified human foods, pet foods, manufactured animal feeds, and extracted products. The insects may be processed into intermediate products delivered to manufacturers as ingredients in producing these products. Nonetheless, typical processing methods of edible insects in Africa have significant influence on functional properties which might influence formulation, downstream processing and the general quality of final products. More research is needed to understand the structure-functionality relationships in insect-derived components such as extracted proteins, oils, or pulverized powders and how functional properties may be optimized for better performance in new product systems.

Finally, to derive the benefits of edible insects at scale, intensification of technologies for rearing rather than wild harvesting should be targeted. This will require species selection based on suitability for mass production, biomass supply, nutritional content, and environmental implications. According to EFSA Scientific Committee (2015), a few out of the many edible insect species are mass-produced in parts of the world. Fly larvae e.g. *H.illucens, M. domestic*a and *Chrysomya chloropyga* (Blow fly) are farmed for feed. Crickets, mealworms, silkworms, grasshoppers and locusts have been farmed commercially for human or pet food. Nonetheless, some challenges in scaling the production and utilization of edible insects need to be overcome, among them, negative perceptions amongst non-traditionally consuming populations. There is also lack of legislative and regulatory frameworks to promote insect use, while at the same time, giving guidelines to handle potential risks. These challenges are partly due to knowledge gaps. The challenges could become resolved as more data becomes available especially with respect to




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postharvest processes. For example, informed by findings of a rigorous research on nutritional value, safety, processing, and feeding trials, a local standard for incorporation of dried insect products in animal feeds was recently developed and registered in Kenya (KEBS, 2017).

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Table 1: Traditional methods of processing and preparation of edible insects for food in various parts of African

| Insect; Country | Stage; source | Processing/ preparation methods |
|---|---|---|
| Tree locust (*Anacridium melanorhodon*); Sudan[1, 2, 8] | Adult; wild | Boiled or fried. |
| Palm beetle (*Oryctes monocerus*); Nigeria[3, 20, 21] | Larvae; wild | Washed, eaten raw, boiled, fried, smoked or roasted, sometimes prepared in stews and soups. |
| *Anaphe infracta;* Nigeria[4] | Larvae; reared/ wild | Roasted, or dry-fried |
| *Anaphe panda;* Congo, Tanzania, Zaire [4, 25] | Larvae; wild/ reared | Roasted, or dry-fried; Cooked fresh or dried and powdered for storage. |
| *Anaphe reticulate*; Nigeria [4] | Larvae; wild/ reared | Roasted, or dry-fried. |
| *Anaphe venata*; Nigeria [4] | Larvae; wild/ reared | Roasted, or dry-fried. |
| *Rhynchophorus palmarum*; Côte d'Ivoire[5] | Larvae; wild | Stewed, fried in oil with salt and pepper, as paste or grilled over coals. |
| *Hemijana variegata* (South Africa)[6] | Larvae; wild | Washed, boiled in salty water, sun-dried. |
| *Microtermes bellicosus*; Nigeria[7] | Adult; wild | Dewinged, roasted and salted or ground into flour. |
| *Rhynchophorus phoenicis* (Nigeria) [9,10] | Larvae; wild | Fried; smoked. |
| *Macrotermes nigeriensis;* Nigeria[11] | Adult; wild | Washed, salted, mildly fried or roasted without oil; also eaten raw. |
| *Ruspolia differens* (green and brown grasshoppers); Kenya[12] | Adult; wild | Dewinged, toasted in own oil; may then be dried; also eaten raw |
| *Macrotermes subhylanus;* Kenya[12] | Adult; wild | Dewinged, toasted in own oil and dried. |
| Mopane caterpillar*;* Zimbabwe[13] | Larvae; wild | Degutted, roasted on charcoal and sun-dried or salted and sundried; packed in sacks or tins to sell to traders or in the market. |
| Melon bug (*Aspongopus vidiuatus*); Sudan[14] | Adult | Oil extracted after soaking in hot water. |
| Sorghum bug (*Agonoscelis pubescens*); Sudan[15, 25] | Adult; wild | Fried or roasted oil extracted for cooking and medicinal purposes. |
| *Melon bug* (*A. vidiuatus*); Namibia[16] | Adult; wild | Milled, used as spices in powder form. |
| Ground cricket (*Henicus whellani*)*;* Zimbabwe[17] | Adult; wild | Degutted, cleaned with cold water, boiled in water. |
| *Encosternum delegorguei;* Zimbabwe[18] | Adult; wild | Killed in warm water, cooked and dried. |
| Ants; Botswana[19] | Adult; wild | Mixed and pounded together with wild vegetables. |
| Harvester termites (*H. mossambicus*); Botswana[19] | Adult; wild | Roasted in hot ash and sand; pounded into a cake. |
| Winged termites (*Hodotermes mossambicus*); Botswana[19] | Adult; wild | Roasted in hot ash and sand. |
| Grasshopper (*R. differens*); Botswana[19] | Adult; wild | Roasted in hot ash and sand after removing head and intestines, sun-dried before storage; pounded in to powder, and eaten with porridge. |
| Hawk moth (*Herse Convovuli*); Botswana[19, 25] | Larvae; wild | Intestines squeezed out, roasted in hot ash and sand sun-dried and stored in bags; may be pounded into powder and mixed with stewed watermelon. |
| *Sternocera orissa;* Botswana[19, 25] | Adult; wild | Roasted in hot ash and sand, hind wings and head may be removed; pounded and mixed with wild fruits and plants to form a paste. |
| Termites; Kenya[20] | Adult; wild | Crushed to a mush and eaten with honey. |
| Palm weevil (*R. phoenicis*)*;* Nigeria [21] | Larvae; wild | Eaten raw, boiled, fried or roasted, sometimes prepared in stews and soups. |
| *Cirina forda;*Nigeria [22] | Larvae; wild | Boiled and dried in the sun. |
| Termites; zambia[23] | Adult; wild | Boiled or roasted, then sun-dried or smoke-dried. |
| *Lepidoptaria litoralia;* Nigeria [24] | Larvae; wild | Boiled in water with a pinch of potash-powder, strained and sun-dried, then salted and seasoned and roasted in oven. |
| Termites; Zambia[24] | Adult; wild | Killed by boiling or roasting for a few minutes, then sun-dried or smoke-dried. |
| *Chaoborus edulis* (Lake fly); Uganda[25] | Adult; wild | Ground to a cake, then sun-dried. |
| Bees; Congo[25] | Larvae, pupae; wild | Grilled. |
| Bees; Tanzania[25] | Larvae; wild | Eaten raw in their combs, shaken out and added with honey to porridge. |
| Ants e.g. *Carebara* spp; Central Africa Republic, Cameroon[25] | Eggs; wild | Raw or fried. |
| *Carebara* ssp.; South Africa[25] | Queen; wild | Gasters removed, eaten raw or fried with salt. |
| Termites; Congo[25] | Adult; wild | Fried in own fat. |
| Termites; Uganda[25] | Adult; wild | Steamed or smoked in banana leaves; sometimes only the heads eaten. |
| Silk worm; Madagascar[25] | Larvae; wild | Killed by dipping in hot water, and then eaten. |
| *Cirina forda;* Mali, Burkina Faso[25] | Larvae; wild | Boiled in water, and then fried in karité butter. |
| Stinking blattid cockroach; Cameroon[25] | Adult; wild | Elythra removed, fried and mixed with porridge of vegetables or fruits. |
| *R. differens;* Uganda[25] | Adult; wild | Antennae, legs and wings removed, then fried |
| *R. phoenicis;* Cameroon[26] | Larvae; wild | Roasting / boiling / smoking / grilling, then dried and milled in to flour. |
| Stinkbugs (*Encosternum delegorguei*)*;* Zimbabwe[27] | Adult; wild | Eaten raw or cooked: head removed, washed, fried or toasted and sun-dried. |
| *Eulepida mashona;* Zimbabwe[28] | Adult; wild | Boiling. |

Sources: [1] Babiker *et al.* (2007a); [2] Babiker *et al.* (2007b); [3] Banjo *et al.* (2006); [4] Defoliart (1995); [5] Dué *et al.* (2009); [6] Egan *et al.* (2014); [7] Ekpo and Onigbinde (2007); [8] El Hassan *et al.* (2008); [9] Elemo *et al.* (2011); [10]Edijala *et al.*, 2009; [11] Igwe *et al.* (2011); [12] Kinyuru *et al.* (2010); [13] Kozanayi and Frost (2002); [14] Mariod *et al.* (2004); [15] Mariod *et al.* (2011); [16] Mustafa *et al.*

(2008); [17] Musundire *et al.* (2014b); [18] Musundire *et al.* (2016a); [19] Nonaka (1996), [20] Ogutu (1986); [21] Onyeike *et al.* (2005); [22] Osasona and Olaofe (2010); [23] Silow (1983); [24] Solomon and Prisca (2012); [25] Van Huis (2003); [26] Womeni *et al.* (2012); [27]Musundire *et al*. (2016a),

[28]Musundire *et al*. (2016b).




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Table 2: Experimental methods of processing insects for animal feed in Africa

| Insect and source (Country) | Processing method | Animal fed | Performance observations |
|---|---|---|---|
| Housefly (*Musca domestica)* larvae reared on poultry droppings (Nigeria)[1] | Washed, killed by immersing in tepid water; defatted or not defatted; oven-dried or sun-dried; milled; mixed with other ingredients, extruded at 80°C under pressure; pellets dried; stored in airtight polyethylene bag at -5°C. | Fish: African catfish (*Clarias gariepinus*) fingerlings | Defatting and drying influenced nutrient density; higher for defatted than full-fat meals. Growth performance and nutrient utilization of oven and sun-dried defatted meals not different; defatted dried meal gave better growth performance and nutrient efficiency. |
| Housefly larvae reared on cow dung (Nigeria)[2] | Boiled (10 min), rinsed with water, sun-dried and milled. | Fish: *C. gariepinus* fingerlings | Increasing maggot meal inclusion beyond 25% resulted in lower growth rate and survival. |
| Housefly larvae reared on fresh blood mixed with wheat bran and sawdust (Nigeria)[3] | Oven-dried, milled; mixed with other ingredients, pelletized and stored in air tight container. | Fish: *C. gariepinus* fingerlings | Up to 75% replacement of fish meal did not elicit adverse effects on feed conversion ratio, weight gain, growth rate, and protein efficiency. |
| Housefly larvae reared on poultry droppings (Nigeria)[4] | Dried, milled, and mixed with other ingredients to form mash. | Poultry: broiler chicken | Processing characteristics, carcass quality and organoleptic properties affected differently by different replacement levels of fish meal. |
| Housefly larvae reared on fresh cattle blood mixed with wheat bran (Nigeria)[5] | Sun-dried and milled using hammer mill; mixed with other ingredients, pelletized using motorized pelletizer; pellets sun-dried. | Fish: *C. gariepinus* | Diets containing 25% maggot meal shows similar performance in growth and nutrient utilization as those containing 25% fish meal. |
| Housefly larvae reared on chicken manure (Nigeria)[6] | Blanched in hot water, oven-dried (80°C) and milled; powder mixed with other ingredients, pasted using hot water and extruded; extrudates sun-dried, stored at -20°C in air tight containers and crushed to suitable-size pellets before feeding. | Fish: Hybrid cat fish fingerlings "Heteroclarias" | 25% substitution for fish meal gave best growth performance; better results when diets contained mixture of maggot and fish meal as compared to pure fish or maggot meal diets. |
| Housefly larvae reared on poultry droppings and fish carcass (Ivory coast)[7] | Maggot meal mixed with other ingredients and mixed with hot water (80°C); paste dried and crushed into powder. | Fish: *Heterobranchus longifilis* larvae | Growth performance and nutrient utilization (weight gain, specific growth rate) increased with increasing maggot meal inclusion (50.5-89%). |
| Housefly larvae reared on chicken waste (Nigeria)[8] | Dried. | Poultry: broiler chicks (1-35 d) | 33% replacement of conventional fish meal (9% fish meal diet) found ideal; did not compromise performance and nutrient retention. Higher inclusion reduced feed intake and weight gain (lower palatability), reduced nitrogen retention and increased fat retention. |
| Housefly larvae (Nigeria)[9] | Live maggots mixed with wheat bran. | Fish: Nile tilapia (*Oreochromis niloticus)* | A 4:1 mixture of wheat offal and maggot gave better growth performance, specific growth rate, feed conversion ratio, and survival than wheat offal alone. |
| Housefly larvae reared on poultry droppings enrich with palm oil (Nigeria)[11] | Sieved and rinsed; roasted, and milled. | Poultry: layers | Replacement (0 -100%) in a 3% fish meal diet did not affect feed intake, egg production, egg weight, feed efficiency. No difference in external egg quality but egg albumen found higher in birds fed diet with equal amounts of fish and maggot meal; cholesterol and calcium decreased with increasing maggot meal. |
| Housefly larvae collected from a commercial layers farm (Cameroon)[12] | Washed, sun-dried and milled. | Poultry: chicken broilers (starter and finisher diets) | Higher weight gain observed when fish meal was replaced (0 – 100%) in a formulation containing 2--4.5% fish meal; no difference in feed conversion ratio and carcass weight; increasing maggot meal tended to increase proportion of liver and gizzard; toxicity tests recommended. |
| Housefly larvae collected from poultry waste (Nigeria)[13] | Washed, oven dried and milled. | Poultry: broilers (one day– 6 weeks old) | No significant difference in growth performance and nutrient utilization with increasing levels of maggot meal (0 -100%); maggot meal could replace up to 100% ground nut cake in a 22% ground nut cake diet. |
| Housefly larvae reared on poultry waste (Nigeria)[14] | Washed and blanched in hot water, oven dried, milled, packed in airtight plastic container, and stored at 4°C. | Fish: *O. niloticus* fingerlings | 50 – 60% replacement of fish meal (28% fish meal diet) gave optimal growth performance, nutrient utilization and survival. |
| Housefly larvae collected from poultry waste (Nigeria)[15] | Washed in tap water, dried, milled. | Poultry: Layers; 50 weeks old laying hens | No effect of fish meal replacement level (0-100% in a 25% fish meal containing diet) on feed intake, weight gain and feed conversion, but affects observed on egg production, shell thickness and shell weight. |
| Housefly larvae reared on poultry droppings (Nigeria)[16] | Dried and milled | Poultry: broiler chicks | 50% replacement (in a 4.0% fish meal diet) gave superior growth performance and feed conversion compared to 100% fish meal diet. |
| Housefly larvae collected from poultry manure (Nigeria)[17] | Boiled, sun-dried, milled; mixed with dried milled rumen contents in a 3:1 ratio. | Pigs: piglets (28 d, weaned) | Tolerated 10% rumen content- maggot meal mixture without any adverse effect on performance. |
| Housefly larvae and pupae reared on bran/ blood mixture (South Africa)[18] | Frozen (-20°C) to kill them; defrosted and oven-dried; milled and mixed with maize meal 1:1. | Poultry: broiler chicks (20 d) | Pupae meal gave significantly higher total tract digestibility of most nutrients than larvae meal. |
| Housefly larvae reared on poultry droppings (Nigeria)[19] | Oven dried, pulverized, compounded with other ingredients, pelleted, pellets sun-dried and stored in non-porous polythene bag. | Fish: *C. gariepinus* juveniles | 50% maggot meal inclusion to replace fishmeal gave better growth and nutrient utilization as compared to lower inclusion levels. |
| Housefly larvae reared on poultry droppings (Nigeria)[20] | Washed with water; fed directly. | Fish: *C. gariepinus* juveniles | Combination of 50% compounded feed and 50% maggots gave best growth performance; higher proportions of maggot reduced growth performance. |
| Housefly larvae reared on mixture of bran and pig blood (South Africa)[21] | Frozen at -20°C to kill the insects, oven-dried oven, milled and compounded with other feed ingredients. | Poultry: broiler chicks | Substitution of fish meal (in a 10% fish meal diet) had positive rather than detrimental effects on carcass quality (carcass weight, breast meat yield), meat quality (colour, pH, water holding capacity, cooking losses) and sensory attributes. |
| Housefly larvae reared on poultry waste (Nigeria)[22] | Washed in water and fed fresh. | Fish: *C. gariepinus* juveniles | A combination of 50% compounded feed and 50% maggots gave highest weight gain and specific growth rate; higher proportions of maggot reduced growth performance. |
| Housefly larvae reared on poultry droppings (Nigeria)[23] | Dry larvae meal mixed with other feed ingredients and oil, moistened, cold extruded and extrudates dried. | Fish: Carp (*Cyprinus carpio*) | Replacement of fish meal with 45--67% maggot meal improved specific growth rate and feed conversion ratio with minor anti-oxidative and biotransformation stress responses in liver and gills. |
| Housefly; larvae reared on poultry droppings (Nigeria)[24] | Larval meal mixed with the other ingredients, sunflower oil and water; dough pressed to pellets; pellets dried. | Fish: *O. niloticus* fingerlings | Total replacement of fish meal (in a 43% fish meal containing diet) did not affect growth and performance; No adverse or stress effect on the hematology and homeostasis. |
| Housefly larvae reared on blood and gut contents of cattle (Ghana)[25] | Fed fresh. | Poultry: chicks | Higher performance (egg weight, number of eggs, and chick weight) as compared to scavenging chicken. |
| Termites (genera *Trinervitermes* and *Noditermes*) collected from the wild (Benin)[26] | Dried and milled into flour or fed directly. | Poultry: chicks, keets | Similar growth and survival compared to conventional feed; some species of termites toxic to chicks and keets. |
| Termite *(Kalotermes flavicollis)* from the wild (DRC)[27] | Sun-dried and slightly roasted, ground to a meal and mixed with other ingredients. | Poultry: broilers (1-56 days) | About 10% substitution of meat meal gave satisfactory result in terms of mean weight gain. |
| Cockroach *(Blatta orientalis)* collected from the wild (DRC)[27] | Killed sun-dried and slightly roasted, ground to a meal and mixed with other ingredients. | Poultry: broilers (1-56 days) | About 10% substitution of meat meal gave satisfactory result in terms of mean weight gain. |
| *Termites (M. subhyalinus)* reproductive adults collected from the wild (Nigeria)[28] | Oven dried (80°C, 3 h), wings blown off, milled, formulated with other ingredients, mixed with starch, gelatinized with hot water to form a dough, pelleted using hand pelleting machine, sun-dried, pellets crushed into crumbs, packed in jute bags, and stored at room temperature. | Fish: Catfish (*Heterobranchus longifilis*) fingerlings. | 50% substitution of fish meal gave best growth rate. |



 

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| Black soldier fly (*H. illucens*) larvae reared on fermenting perm kernel cake (Republic of Guinea)[29] | Direct feeding of live larvae | Fish: *O. niloticus* | Improved growth rate with diet of 30% *H. illucens* and 70% rice bran on dry matter basis compared to rice bran meal alone. |
| *Cirina forda* larvae purchased from local market (Nigeria)[30] | Sun-dried, milled, and compounded with other ingredients. | Poultry: broiler chicks | Partial or complete replacement of fish meal (4% fish meal diet) did not affect feed consumption, weight gain or specific growth rate. |
| *C. forda* larvae obtained from local open air market (Nigeria)[31] | Oven-dried, milled and compounded with other ingredients. | Poultry: layers | Up to 75% replacement of a 4% fish meal containing diet did not affect feed intake, weight gain, egg production, feed efficiency and egg quality characteristics; 100% replacement reduced egg production, egg weight and feed utilization efficiency. |
| Silkworm (*Anaphe infracta*) larvae collected from wild (Nigeria)[32] | Blanched in hot water, sun-dried and milled. | Poultry: broilers | Complete replacement of fish meal did not affect feed intake, body weight gain, feed conversion efficiency and protein efficiency ratio; no adverse effects on carcass characteristics and hematological parameters. |
| Mopane worm larvae collected from the wild (Botswana)[33] | Dried and milled (*phane* meal). | Poultry: guinea fowl keets (2 -13 weeks) | Inclusion level up to 4.5% did not affecting growth |
| Mopane worm larvae collected from the wild (Botswana)[34] | Dried and milled (*phane* meal). | Poultry: Broilers (2-7 weeks) | 40% inclusion in diet gave lower weight gain but meat with lower fat, higher ash and higher organic matter and improved palatability. |
| Cheese fly (*Piophila casei*) larvae reared on cheese (Egypt)[35] | Washed, killed in tepid water, oven-dried (36 h, 60°C); milled; mixed with other ingredients, oil, water, made to pellets 1 mm); pellets dried. | Fish: *O. niloticus*) fingerlings | 100% replacement of fish meal in a 20% fish meal diet gave good growth performance and nutrient utilization. |
| Grasshopper (Nigeria)[36] | Dried and milled to produce grasshopper meal; mixed with other ingredients. | Poultry: broilers | 100% replacement of fish meal (5% fishmeal diet) gave higher weight gain and feed intake but lower feed conversion efficiency as compared to the full fish meal diet. |
| Variegated grasshopper (*Zonocerus variegatus*) collected from wild (Nigeria)[37] | Boiled, sun dried, de-winged and milled in a hammer mill and sieved. | Fish: *C gariepinus*); fingerlings | 25% fish meal replacement (in a 31% fish meal diet) did not have adverse effect on growth and nutrient utilization. Above25% replacement decreased protein and lipid digestibility and performance; carcass lipid also decreased; processing to reduce the chitin level recommended. |
| Desert locust (*Schistocerca gregaria*) purchased from local market (Nigeria)[38] | Sun-dried and ground into a meal. | Fish: *C. gariepinus*); juveniles | 25% dietary protein replacement (40% protein diet) attained without significant reduction in growth performance; Chitin thought to have contributed to lower performance and feed efficiency when greater rates were used. |
| Migratory locust (*Locusta migratoria*) harvested from the wild (Nigeria)[39, 40] | Dried, milled. | Fish: *O niloticus*) fingerlings | 25% replacement of fish meal did not show adverse effect on nutrient digestibility, growth performance, and hematological parameters. |

Sources: [1] Fasakin *et al.* (2003); [1]Idowu *et al.* (2003); [3] Salau (2013); [4] Okubanjo *et al.* (2014); [5] Aniebo *et al.* (2009); [6] Sogbesan *et al.* (2006); [7] Ossey *et al.* (2014); [8] Atteh and Ologbenla (1993); [9] Ebenso and Udo (2003); [11] Akpodiete *et al.* (1998); [12] Téguia *et al.* (2002); [13] Adeniji (2007); [14] Ezewudo *et al.* (2015); [15] Agunbiade *et al.* (2007); [16] Okah and Onwujiariri (2012); [17] Adeniji (2008); [18] Pieterse *et al.* (2014); [19] Idowu and Afolayan (2013); [20] Oyelese Oyelese (2007); [21] Pieterse *et al.* (2014); [22] Kareem and Ogunremi (2012); [23] Ogunji *et al.* (2011); [24] Ogunji *et al.* (2008); [25]Dankwa *et al.* (2002); [26] Chrysostome (1997); [27] Mushambanyi and Balezi (2002); [28] Sogbesan and Ugwumba (2008); [29] Hem *et al.* (2008); [30]Oyegoke *et al.* (2006); [31]Amao *et al.* (2010); [32] Ijaiya and Eko (2009); [33] Nobo *et al.* (2012); [34] Mareko *et al.* (2010); [35] Ali *et al.* (2015); [36] Hassan *et al.* (2009); [37] Alegbeleye *et al.* (2012); [38] Balogun (2011); [39] Abanikannda (2012); [40] Emehinaiye (2012).

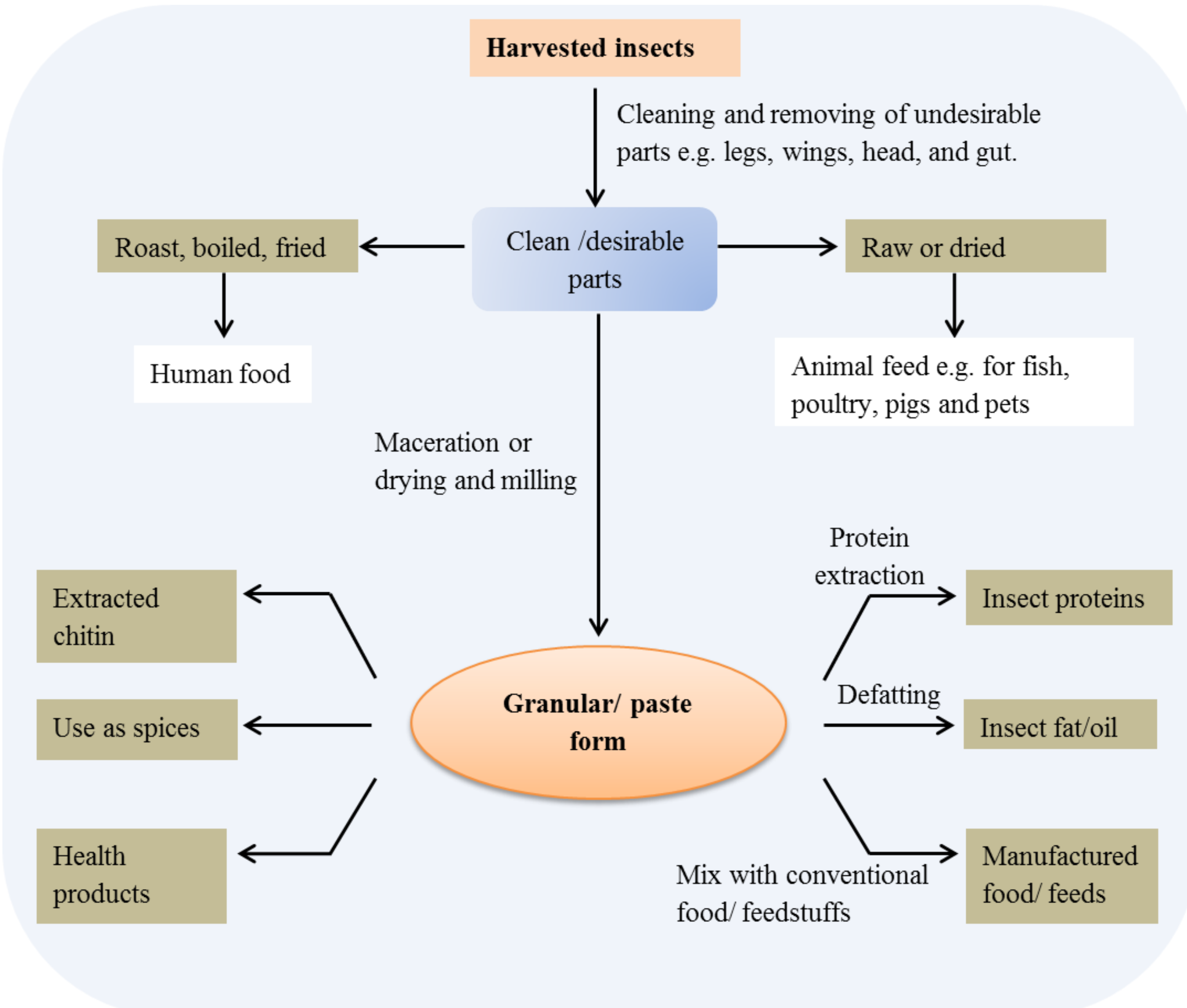


Figure 1: Schematic presentation of the utilization of edible insects