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Insects used for animal feed in West Africa

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Abstract

In West Africa, as in many parts of the world, livestock and fish farming suffer from the increasing cost of feed, especially protein ingredients, which are hardly available for village poultry farming and small-scale fish farming. Insects, which are a natural food source of poultry and fish and are rich in protein and other valuable nutrients, can be used to improve animal diets, a practice which is now strongly promoted by the FAO as a tool for poverty alleviation. This paper reviews practices and research on the use of insects as animal feed in West Africa and the perspectives to further develop the techniques, in particular for smallholder farmers and fish farmers. The most promising insects are flies, especially the house fly (*Musca domestica*) (Diptera Muscidae) and the black soldier fly (*Hermetia illucens*) (Diptera Stratiomyiidae), which can be mass reared on-farm for domestic use, in small production units at the community or industrial level. Flies have the advantage over most other insects of developing on freely available waste material and could even contribute to rural sanitation. Termites are traditionally used by smallholder farmers to feed village poultry. While their mass production is problematic, methods to enhance populations on-farm and facilitate collection can be developed. In any case, new methods will need to demonstrate their economic profitability, social acceptability and environmental sustainability.

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Introduction

Global demand for animal-source foods is accelerating rapidly due to population growth and economic development, particularly in developing countries (Godfray *et al.*, 2010). In most animal production systems, feed takes the largest part of the costs. Fish meal and leguminous crops such as soya are key ingredients in animal feeds since they provide the necessary protein compounds. Most animals, in particular monogastrics, require proteins to compensate the inability to synthesize specific amino-acids. However, conventionally used protein ingredients are not ecologically or economically sustainable (Barona *et al.*, 2010; FAO, 2012). The issue is especially severe in rural West Africa, where feed compounds, in particular proteins, are scarce or unaffordable for smallholder farmers and fish producers. Indigenous poultry farming is practiced by almost all farmers in West Africa. Their main challenge is the increasing cost of feed, which represents up to 70% of the total production costs (Omole *et al.*, 2005). A key issue is the limited availability of common protein ingredients (fish meal, groundnut cake and soybean) that have become particularly expensive. Scavenging poultry farming of poor households particularly suffers from quantitative and qualitative food shortages and, consequently, the productivity is very low (Hardouin, 2003; Pousga *et al.*, 2005). Similarly, to feed their fish, smallholder fish farmers rely on natural productivity, *i.e*. phyto- or zooplankton, of the water bodies, or fertilize the ponds using manures or agricultural by-products. The nutritional value of these kinds of feed and feeding systems is low, which results in slow growth and poor yield (Rhodes University, 2010).

A solution to develop sustainable and productive household aviculture and aquaculture systems includes the use of local, easily available and cheap protein sources, preferably not used for other purposes. Insects, which are a natural food source of free range poultry and fish, provide a sustainable alternative to traditional protein sources (Hardouin & Mahoux, 2003). Insect larvae and pupae are typically rich in protein (40-70% dry weight), mono- and/or polyunsaturated fatty

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acids, other valuable nutrients such as iron, copper, magnesium, manganese, phosphorous, selenium, zinc, B vitamins and essential amino acids such as lysine and tryptophan (DeFoliart 1995; Rumpold & Schlüter, 2013) and can be mass produced regionally and even on-farm (Hardouin & Mahoux, 2003). The FAO strongly recommends the use of insects as human food and animal feed as a tool for poverty alleviation (FAO 2010; van Huis *et al.*, 2013). Many insects are potentially suitable for animal feed (van Huis *et al.*, 2013). In many parts of the world, *e.g.* Asia, several insect species have been used as complementary food sources, in particular for poultry (Ravindran & Blair, 1993; van Huis *et al.* 2013). In West Africa, when available, several insect species are opportunistically given to livestock by farmers during outbreaks (*e.g.* grasshoppers). However, few insects are provided as feed in routine animal husbandry. Exceptions include termites and maggots. This paper reviews the use of insects as animal feed in West Africa with examples from Central African countries when appropriate. It covers research being carried out in the region, and perspectives on how to further develop the techniques, in particular for smallholder farmers and fish farmers.

Termites

Termites are highly nutritious insects (Redford & Dorea, 1984; Sogbesan & Ugwumba, 2008; Ntukuyoh *et al.*, 2012). Throughout West Africa, they are collected in the bush to feed poultry. For example, 72% of the farmers in South-Western Burkina use termites to feed poultry (Diawara, 2013). Chippings of termite mounds or underground nests are collected and given to poultry on-farm, particularly to chicks and keets (young guinea fowls). This activity is often done by children who sometimes also sell the chippings to other users. Termites are not equally available in all regions and seasons, and in many cases collectors have to walk long distances to find sufficient amounts of termites to feed the farm animals. The difficulty of finding termites sometimes forces farmers to abandon this ancestral technique (Diawara, 2013).

According to farmers, not all termites are appropriate for poultry feed. For example, in Burkina Faso, some species of *Cubitermes* are reported as toxic to chicks, but not to guinea fowls and ducks (Diawara, 2013). In a feeding trial with chicks and keets in Benin, Chrysostome (1997) showed that a humivorous species of the genus *Noditermes* was toxic to both poultry species, in contrast to a xylophagous species, *Trinervitermes* sp., confirming farmers' knowledge. Feeding keets and chicks with the nontoxic species resulted in similar growth and survival compared to conventional feed.

Termites cannot be easily produced and moreover, their rearing produces high amounts of methane, an important greenhouse gas. However simple methods have been developed to increase the number of termites available on farm. Farina *et al.* (1991) and Vorsters *et al.* (1994) describe in detail methods used in Togo and Benin, which is based on fibrous and humidified waste or crop residues placed in clay pots or baskets, which are then inverted and placed on small termite nests. The pots are moistened regularly and protected from excess heating. Termites are collected in the pots after three to four weeks. Chrysostome *et al.* (2009) describe a similar technique used in Benin for collecting termites for keets. Maize or sorghum straw are placed in empty palmyra palm nuts (*Borassus* spp.), which are then put in moistened pots filled with bark pieces of locust bean (*Parkia biglobosa*) and sorghum straw. The pots as placed on nontoxic termite nests. The day after, termites are collected in the nuts and given to keets, preferably with grains. Other, similar techniques used in Burkina Faso are described in Diawara (2013).

To our knowledge, the only quantitative study on the effect of a termite diet on poultry growth in West Africa is that of Diawara (2013) in Burkina Faso. She substituted fish meal by fresh termites of the genus *Macrotermes* in chick diets without affecting the daily weight gain, although the feed conversion ratio was significantly higher with termites compared to fish meal. Similarly, Munyuli Bin Mushambanyi & Balezi (2002) showed, in the Democratic Republic of the Congo, that chick feed portions containing 12% of termite (*Kalotermes flavicollis*) meal gave satisfactory result in terms of mean weight gain and were economically much more profitable than conventional meat meal.

Termites are also used occasionally by smallholder fish farmers, although it is not clear to what extent this practice occurs in West Africa. In Uganda, about five per cent of fish farmers use termites as supplementary feed (Rutaisire, 2007). Termites are either collected directly or purchased from collectors at a cost of US Dollars 0.27/kg (at 2004 value). The quantity available depends on, among other things, the season, the availability of termite mounds and the termite species. On average, a termite mound provides about 50 kg of termites per year (Rutaisire, 2007).

Reproductive winged termites swarm in very high numbers at the onset of the rainy season or after heavy rainfall. Fish are often observed consuming winged termites when they fall into ponds. Sogbesan & Ugwumba (2008) suggested that they could be used to prepare termite meal as a replacement to fish meal. They tested termite meal from oven-dried reproductive adults of *Macrotermes subhyalinus* and obtained excellent results on fingerlings of *Heterobranchus longifilis*, a commonly cultured catfish in Nigeria. The best results, in terms of growth rate and benefit-cost ratio, were obtained when combining 50% termite meal with 50% fish meal.

House fly larvae

Two species of flies have been extensively studied worldwide for their use in livestock feed; the domestic fly *Musca domestica* (Muscidae) and the black soldier fly *Hermetia illucens* (Stratiomyidae). In West Africa, *M. domestica* is more commonly used because of its prevalence in most habitats, its fast development, and the possibility of obtaining high numbers of maggots and pupae naturally on various substrates without having to rear adults for egg laying.

There is an extensive literature from West Africa on the suitability of maggots or pupae of *M. domestica* to rear chicks and broilers (Atteh & Ologbenla, 1993; Bamgbose 1999; Akpodiete & Inoni 2000; Téguia *et al.*, 2002; Awoniyi *et al.* 2003; Adeniji, 2007; Adesina *et al.*, 2011), layers (Akpodiete *et al.*, 1998; Agunbiade *et al.*, 2007; Okah & Onwujiariri 2012), ducklings (Mensah *et al.*, 2007), piglets (Adeniji, 2008), catfish species (Fasakin *et al.*, 2003; Idowu *et al.*, 2003; Madu & Ufodike, 2003; Sogbesan *et al.*, 2006; Oyelese 2007; Aniebo *et al.*, 2011; Olele 2011; Kareem & Ogunremi, 2012; Ossey *et al.*, 2012), Nile tilapia (Ebenso & Udo, 2003; Ogunji *et al.* 2006, 2007; 2008a; 2008b; 2009; Omoyinmi & Olaoye 2012), carp (Ogunji *et al.*, 2011) and African giant snail (Mbunwen *et al.,* 2011). In all cases, these studies showed that maggots, either fresh or dried, could entirely or partially replace conventional protein ingredients such as fish meal, meat meal or groundnut cake without affecting survival, daily feed intake, weight gain, feed conversion ratio, egg laying and other performance factors. Some studies showed better results with maggot meal than with conventional fish meal (*e.g.* Téguia *et al.*, 2002). However, when various proportions of maggot and fish, or maggot and meat meals were used, the best growth performance was often observed with variable combinations of maggot meal and conventional meal than with a single protein source. This may be because the combination of maggot meal with conventional feed might provide a more balanced diet for the animals. For example, Atteh & Ologbenla (1993) found that a 33% replacement of conventional fish meal by maggot meal is ideal for chicks, but higher proportions of maggots reduced

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feed intake and growth. However, they used processed maggots, which has a dark color, and suggested that the observed reduction in feed intake associated with an increase in maggot meal proportions may simply be due to changes in feed color. In some cases, the optimum proportion depends on the age of the animals. Awoniyi *et al.* (2003) found better results by replacing conventional fish meal with 25% maggot meal than with 100% replacement in older broilers, while young broilers had no reduction in growth with a total replacement compared to mixtures. Similarly, in fish feeding tests, several authors found better results when giving a mixture of fish and maggot meal than with one protein source alone (Sogbesan *et al.*, 2006; Madu & Ufodike, 2003; Oyelese, 2007; Kareem & Ogunremi, 2012).

In some cases, further processing maggot meals may be beneficial. Fasakin *et al.* 2003 showed that catfish performed better when fed diets containing defatted maggot meals than full-fat maggot meal, and compared favorably with fish fed the fish meal-based diet. Adding other supplements may also increase performances. Bamgbose (1999) showed that maggots can completely replace meat meal in diets for cockerel chicks without any adverse effect on performance and nutrient utilization, but that supplementation with methionine (0.20%) enhanced nutrient utilization and performance significantly.

Many of the above cited studies also mentioned an economic benefit in the replacement of conventional protein sources by maggots (*e.g.* Atteh & Ologbenla, 1993; Akpodiete & Inoni 2000; Téguia *et al.*, 2002; Sogbesan *et al.* 2006; Oyelese 2007; Okah & Onwujiariri 2012). Cost saving can be substantial. For example, Atteh & Ologbenla (1993) calculated that maggot meal represents only about 15% of the value of fish meal and Akpodiete & Inoni (2000) increased the net return of broiler production by 15% when replacing 75% of fish meal by maggot meal. However, none of these studies provide adequate economic analyses because maggots were produced for the purpose of the experiments, in very small quantities and without attempt to minimize production costs or to assess the potential costs of larger production systems. These studies also virtually focused exclusively on industrial or semi-industrial battery poultry and fish production, where protein ingredients are always included in diets. In contrast, free-range domestic fowls scavenge around the farm, in streets and in the bush, where protein sources are rare. In such case, providing maggots or other insect-feed is even more profitable, but quantified studies in these environments are rare. An exception is that of Dankwa *et al.* (2002) in Ghana, who observed a significant increase in performance in chickens (clutch size, egg weight, number of eggs, hatched, and chick weight) fed with larvae compared to scavenging chicken.

There are few publications on fly rearing techniques in West Africa (Aniebo *et al.*, 2008b). Most studies focusing on the use of domestic flies as animal feed cited in the preceding paragraphs obtained maggots by exposing small quantities of various substrates to naturally occurring flies. Larger scale production systems from Benin (Nzamujo, 1999) and Mali (Koné, 1998) have been described but the recommendations have not been substantiated by research data. The production systems are based on the exposure of substrates, placed on rearing beds directly on the soil, to attract adults for oviposition. A few days later, the substrate is sifted or brushed to extract mature maggots, which are either sun dried or given fresh to the animals. About 10-15 kg of dry matter in 1×1×0.1 m beds produce up to 3 or 4 kg of fresh maggots in 4 days (Nzamujo, 1999; Koné, unpublished data), but yields greatly vary with seasons and substrates. This system can be done at a small scale to feed a few chickens or at a larger scale to feed chicken or fish production farms. Rearing substrates have to be attractive for adults and suitable for maggot development. The most common substrates include poultry or other animal manure, animal offal, rumen content, brewery waste, decaying fruits, etc. Using a similar technique, Aniebo *et al.* (2008b) used cow and goat blood from a Nigerian abattoir and mixed the blood with wheat bran, rice dust and saw dust. Mixtures of 25 kg blood and 5 kg wheat bran yielded an average of 7.16 kg of fresh maggots. They calculated that the abattoir could potentially produce nearly 2 tons per day. Abattoirs can also provide rumen content, which is also highly suitable for maggot rearing (Loa, 2000). In Côte d'Ivoire, Bouafou *et al.* (2006) tested different animal and vegetal substrates as attractants for flies. They found that animal offal attracted much more flies for oviposition and produced much more larvae than fermented vegetal substrates. They also found more *Calliphora* spp. (blow flies – Calliphoridae) than *Musca* spp. in most samples, including some vegetal substrates. This suggests that many feeding trials carried out in the region and based on naturally exposed substrates have contained a certain amount of blow flies. However, Bouafou *et al.* (2006) did not test manure, which is the most commonly used rearing substrate in the published studies. Mpoame *et al.* (2004) exposed chicken manure and cow dung for fly oviposition and maggot production in Cameroon. They found out that chicken manure was much more efficient and obtained exclusively Muscidae of various but undetermined species. Loa (2000) reared only *M. domestica* and two individuals of *Musca sorbens* from rumen contents in Cameroon.

Studies on the chemical composition and nutrition parameters of house fly maggots and pupae are numerous and have been recently compiled by Awoniyi (2007), Bouafou (2011) and Heuzé & Tran (2013a). Although results often varied significantly between studies, partly because the production methods were also variable, all studies show that maggots have a high crude protein content (40 to 60% DM) and lipid content (9 to 25% DM). Research data from West Africa are available, *e.g.,* in Awoniyi (2007), Bouafou (2007), Aniebo *et al.* (2008a), Aniebo & Owen (2010) and Odesanya *et al.* (2011). Aniebo *et al.* (2008a) analyzed the nutrient composition of house fly maggots, in particular, crude protein, fat, fiber, ash and amino acid contents. They found that lysine and methionine, which are the two most limiting essential amino acids, were found to be higher in maggot meal than in fish meal and other conventional protein sources. However, the content changes with the drying method and with the age of the maggots; protein contents decreases and fat content increases with age (Aniebo & Owen, 2010).

The sanitary risks related to house fly utilization in animal feed have been rather poorly investigated in Africa and elsewhere. Risks may occur for the animals themselves, for the consumers and for the breeders and populations in contact to rearing systems. Bouafou *et al.* (2011) showed that maggot meal could be toxic to rats, causing histological and histopathological damages. To our knowledge, this has not been demonstrated for poultry or fish. High proportions of maggot meals in poultry diet increased the mass of liver and gizzard (Téguia *et al.*, 2002), but Pretorius (2011) did not observe the same effects on gizzard nor any toxicity effect using similar maggot meal diets. However, mass mortality of keets has been reported by farmers when they fed on maggots from decaying animals (Teye & Adam, 2000), but the causal effect was not investigated. Fresh maggots and maggot meals contain various pathogenic microorganisms, as observed in Nigeria by Banjo *et al.* (2005) and Awoniyi (2007), respectively. Storage may increase the amount of pathogenic fungi and bacteria in maggot meals, especially if the moisture content is too high (Awoniyi *et al.*, 2004). In his review, Awoniyi (2007) concluded that the inclusion of maggot meal in the poultry diet is microbiologically safe for the animal and the consumer, based on the facts that the same bacteria were isolated from chicken fed with various proportions of maggot meal and that the bacteria encountered in maggot meals are not really different from those encountered by animals and humans during their daily exploits. Nevertheless, health issues related to fresh maggots or maggot meals in animal feed should be further investigated. Adults of the house flies are known to transmit various animal and human diseases around the breeding facilities through carrying viruses, bacteria and protozoan parasites and tapeworms (Service, 1980; Ugbogu *et al.*, 2006). Observations suggest that the exposure of substrates on farm in small maggot production systems does not increase house fly adult populations (Koné, unpublished data), but this needs to be verified appropriately.

Black soldier fly larvae

Black soldier flies, *Hermetia illucens* (Diptera Stratiomyiidae) have been tested and used extensively in many parts of the world to feed animals, particularly fish (Bondari & Sheppard, 1987; St-Hilaire *et al.*, 2007), but also swine (Newton *et al.*, 1977) and poultry (Hale, 1973). However, this is not yet a common practice in West Africa. In Nigeria, Oluokun (2000) compared *H. illucens* larvae with soybean meal and fish meal on broiler production. The nutritional profile of maggots is comparable to fishmeal and, in some aspects, better than soybean meal. The author suggested that maggot meal could replace fish meal to upgrade the nutritive value of soybean meal in the broiler rations without any adverse effect on the weight gain, feed consumption and *feed:gain* ratio. Hem *et al.* (2008) tested the use of *H. illucens* for fish farming in Guinea. Maggots were obtained from natural oviposition on fermented palm kernel meal in open tanks. A diet of 30% *H. illucens* and 70% rice bran, based on dry matter, was given to tilapias and the growth rate was very satisfactory. The limiting factor was the low amount of larvae obtained through natural oviposition. However, more efficient rearing systems, including adult rearing and egg production, are available in other parts of the world (*e.g.* Newton *et al.*, 2005; Hem, 2011). These systems could be easily adapted for West African situations and implemented at the farm or community level. A rearing system for *H. illucens* is presently being developed in Ghana as part of PROTEINSECT, an EU funded project (http://www.proteinsect.eu).

Caterpillars

Caterpillars, *i.e.* lepidopteran larvae, are more commonly used for human consumption than for animal feed, including in West Africa (van Huis, 2003, 2013). *Cirina forda* is a moth whose caterpillars defoliate shea trees, *Vitellaria paradoxa*, and which is commonly used in some parts of West Africa for human consumption. It is present only in the rainy season, during which enormous quantities can be harvested. In Nigeria, Oyegoke *et al.* (2006) evaluated the dietary potentials of the larvae of *Cirina forda* as poultry feed. They determined the performance of broiler chicks to the total or partial (50%) replacement of fishmeal with the larvae of *Cirina forda*. They showed that the consumption rate, the mean weight gain and the specific growth rate of chicks fed entirely or partly with caterpillars did not differ significantly from those fed with conventional fish meal. Amao *et al.* (2010) evaluated *Cirina forda* larva meal on laying performance and egg characteristics of hens in Nigeria and concluded that it can replace up to 75% fish meal in the diet of laying hens without affecting feed intake, weight gain, egg production, feed efficiency and egg quality characteristics. At 100% replacement, however, daily egg production, egg weight and efficiency of feed utilization were significantly reduced. In the same country, Ijaiya & Eko (2009) gradually substituted fish meal with silkworm, *Anaphe infracta*, caterpillar meal in broiler chicken feed. There was no significant difference in feed intake, body weight gain, feed conversion efficiency and protein efficiency ratio between the different treatments. They also determined that caterpillar meal was more cost effective than conventional fish meal. In Southern Africa, the caterpillar of the mopane moth, *Imbrasia belina*, also commonly consumed by humans, has been tested and used successfully for poultry feed (Moreki *et al.*, 2012).

Grasshoppers and crickets

Extensive research has been carried out on the use and mass rearing of grasshoppers and crickets, particularly in Asia (Heuzé & Tran, 2013b; van Huis *et al.*, 2013). In West Africa, locusts and grasshoppers are used to feed animals on an opportunistic basis during outbreaks but recent studies in Nigeria have also considered their regular utilisation and nutritional properties for poultry and fish feed. Ojewola *et al.* (2005) and Adeyemo *et al.* (2008) investigated the nutritional potential of unspecified field-collected grasshoppers and desert locusts (*Schistocerca gregaria*), respectively, to replace fish meal as a protein source in broiler chicken diets. These experiments showed that locusts have a great potential as a more expensive protein source in broiler diets without reducing growth or causing physiological disorders. Another study, however, observed that undetermined grasshopper meal may depress weight gain and feed efficiency in broilers (Ojewola *et al.*, 2003). Recent tests also showed that grasshopper meal could be integrated satisfactorily into African catfish feed (Nnaji & Okoye, 2005 using unspecified grasshoppers; Alegbeleye *et al.*, 2012 using *Zonocerus variegatus*) and Nile tilapia (Okoye & Nnaji, 2005, using unspecified grasshoppers; Abanikannda, 2012; Emehinaiye, 2012, both using *Locusta migratoria*). All of these fish nutrition studies replaced fish meal with grasshopper meal in various proportions. Low proportions of grasshopper meal, *i.e.* up to 25% replacement of fish meal, provided similar or higher performances compared to fish meal, whereas higher proportions of grasshopper meal reduced growth and digestibility, possibly due to the lower protein value and higher level of crude fibre in grasshopper meal (Nnaji & Okoye, 2005; Okoye & Nnaji, 2005; Alegbeleye *et al.*, 2012; Heuzé & Tran, 2013b). The nutrient composition of grasshopper meal was assessed by Ojewola *et al.* (2003), Ojewola & Udom (2005), Adeyemo *et al.* (2008) and Alegbeleye *et al.* (2012). Data from these and other studies, summarized in Heuzé & Tran (2013b), were highly variable, *e.g.* with crude protein content varying from 29 to 66%, probably because various species, developmental stages and processing methods were used. All studies on the use of grasshoppers as animal feed in West Africa have been made with field collected or laboratory reared grasshoppers. No production method for large scale production is described. Descriptions of tested production systems are available from other regions (Heuzé & Tran, 2013b; van Huis *et al.*, 2013).

Other insects

To our knowledge, no other insect species have been considered as permanent ingredients in animal feed in West Africa. In other regions, examples are more numerous. Mealworms, particularly *Tenebrio molitor*, have been the target of several studies in various areas of the world, *e.g.* Ramos Elorduy *et al.* (2002), for poultry and Ng *et al.* (2001) for fish. In East and Southeast Asia, larvae of chironomid flies are sold as live feed for aquarium fish and carnivorous fish (Shaw & Mark, 1980; Hardouin & Mahoux, 2003). In DRC, Munyuli Bin Mushambanyi & Balezi (2002) have successfully mass produced cockroaches, *Blatta orientalis*, on poultry manure and used them satisfactorily as replacement for meat meal in poultry diet. More examples of insects used as animal feed elsewhere in the world are found in van Huis (2013) and van Huis *et al.* (2013)

Perspective for the use of insects as animal feed in West Africa

Many insects could potentially be used as a protein source to improve animal feed quality in West Africa and, indirectly, to improve food secu-

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rity. In the short term, the most promising insects appear to be flies, which can be reared on freely available organic waste material, in contrast to other insects such as grasshoppers, caterpillars and mealworms, which have to be produced on plants or plant products. Termites also need to be considered since they have been widely used in village poultry farming in the region for a long time. However, several issues remain and more research is needed before insects become widely adopted as a component of animal feed.

House flies are easy to rear and maggots can be produced in large quantities, as shown by recently developed industrial production systems in other parts of the world (Čičková *et al.*, 2012; Coghlan, 2012). While similar industrial maggot-meal production systems could also be developed in West Africa for large-scale meat and fish producers, smallholder farmers and poor rural communities could adopt small-scale production systems on farm or at the community level by naturally exposing of organic waste substrate (Nzamujo, 1999; Hardouin & Mahoux, 2003). Alternatively, simple adult rearing systems could provide the basis for community production systems that would distribute live or dry maggots to farmers. Priority research topics to allow the development and wide adoption of house fly maggots as feed include the following:

– Firstly, on-farm production systems need to be optimized. In particular, the most efficient and cost-effective substrates for maggot rearing need to be defined for the different eco-climatic regions and for the different seasons. Substrates need to be free, easily available and, if possible, accessible in all seasons. The use of domestic waste for fly rearing should also be considered for improving waste disposal and included in the environmental impact assessments of the production systems. Similarly, by-products of the fly rearing systems (substrate residues) can be excellent fertilizers or soil conditioners, but their quality is clearly variable and should be tested.
– Secondly, to develop small production units based on adult fly rearing for rural communities, the challenge will be to find simple methods for enhancing oviposition, egg collecting, larval extraction from the substrates and drying/storing. These methods are already partly available from systems used in Africa and elsewhere (Spiller, 1963; Hogsette, 1992; Koné, 1998; Nzamujo, 1999; Čičková *et al.,* 2012) but could be improved or adapted for such rural production units.
– Thirdly, thile the nutritional properties and qualities of the house fly maggot are well known (see Bouafou, 2011; Heuzé & Tran, 2013a, and this review), its suitability for some poultry species (*e.g.* guinea fowl, quails) and fish species needs to be further assessed. Furthermore, most studies on poultry were made with battery chickens and few data have been collected on their use with free range, scavenging poultry (Dankwa *et al.*, 2002). For example, a specific issue for scavenging village poultry is the acceptability of dried insects compared to other available food sources, which should be assessed through behavioral tests.
– Finally, using house flies also implies some safety issues since these are known to carry various animal and human diseases (Ugbogu *et al.*, 2006). Although non-quantified observations suggest that the exposure of substrates on-farm to attract flies in small maggot production systems does not increase house fly populations (Koné, unpublished data), this needs to be ascertained through rigorous measurements. The presence of animal diseases in maggot-based feed and the microbiological safety of the obtained meat product should also be investigated.

Black soldier flies have different properties. Specifically, since adults do not feed, they are much less prone than house flies to be vectors of pathogens and they are, thus, particularly safe. On the other hand, they grow more slowly than house flies and a continuous production system requires the rearing of adults in cages, which makes it less suitable for smallholder farmers with scavenging poultry. Nevertheless, it can be envisaged for poultry farmers and fish farmers. As for the house flies, techniques of adult and larval rearing, larval extractions, drying and storing need to be adapted to rural conditions of West Africa.

Termites cannot be easily mass reared and are known to produce methane, an important greenhouse gas (Hackstein & Stumm, 1994). Therefore, large production systems cannot be envisaged. However, methods to facilitate termite collections on farm are already applied and could be further developed. Furthermore, the traditional use of termites as animal feed in West Africa is rather poorly known. Some termite species are known to be toxic to poultry but information is lacking for most species. Indigenous knowledge on this topic and on the use of termites as animal feed in general, should be investigated for the whole region. Indigenous knowledge should be confirmed by feeding tests as in Chrysostome (1997) and the causes of toxicity should be investigated.

No matter the insect species used, for each system using insects as feed, economic assessments need to be carried out and compared to the traditional system since only economically profitable methods are likely to be adopted. Furthermore, although insects represent a natural feed for animals in rural areas; the acceptability of eating animals fed with insects may have to be improved among some urban consumers. Finally, national policies on the use of insect-based animal feed are largely lacking. Therefore, there is a need to promote the use of insects as animal feed within the context of national policies on agriculture, nutrition, health, environment and development.

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