BRILL
WAGENINGEN
ACADEMIC

JOURNAL OF INSECTS AS FOOD AND FEED (2024) DOI:10.1163/23524588-00001232

Journal of Insects as Food and Feed
brill.com/jiff

REVIEW ARTICLE

From traditional to industrial use of insects as feed: a review

A. van Huis[1*], *C.I. Rumbos*[2], *D.G.A.B. Oonincx*[3], *S. Rojo*[4], *A. Kovitvadhi*[5] and *L. Gasco*[6]

[1]Laboratory of Entomology, Wageningen University & Research, Droevendaalsesteeg 1, 6708 PB Wageningen, the Netherlands; [2]Laboratory of Entomology and Agricultural Zoology, Department of Agriculture, Crop Production and Rural Environment, University of Thessaly, 38446 Volos, Greece; [3]Animal Nutrition Group, Wageningen University and Research Centre, De Elst 1, 6708 WD Wageningen, the Netherlands; [4]Department of Environmental Sciences and Natural Resources, University of Alicante, P.O. Box 99, 03080 Alicante, Spain; [5]Department of Physiology, Faculty of Veterinary Medicine, Kasetsart University, 50 Ngamwongwan Rd, Chatuchak Bangkok, 10900, Thailand; [6]University of Turin, Department of Agricultural, Forest and Food Sciences, Largo P. Braccini 2, 10095 Grugliasco, Italy;
*arnold.vanhuis@wur.nl
Received 7 April 2024 | Accepted 16 June 2024 | Published online 18 July 2024

Abstract

Insects are part of the natural diet of fish and poultry species and to a lesser extent of pigs, dogs and cats. In traditional farming, poultry gather their food in a free roaming manner, and insects are part of the diet. Similarly, a large fraction of the diet of freshwater fish consists of aquatic insects. These features are exploited by farmers all over the world, as feed costs are high. For example, farmers lure termites to baskets filled with organic matter, and the insects are then fed to chickens. They also employ light sources above fishponds to attract insects for their fish. More sophisticated methods are, for example, attracting naturally occurring houseflies to containers filled with organic waste, e.g. manure. The captured maggots or pupae are then fed to poultry. We discuss the following insect groups as feeds for poultry, pigs, fish, dogs and cats: bees, caterpillars, cockroaches, flies, grasshoppers and termites. Feed for poultry can also consist of insect pests, which are then controlled at the same time, for example ducks to control rice pests. Moreover, leftovers from the silk industry can be used to feed chickens, pigs and fish. Insects are also commonly used as bait for fishing. The interest in a more industrial production of insects such as the black soldier fly and housefly as animal feed started in the 1970s. In the last 15 years, large-scale rearing of insects for animal feed has taken off, with the industry receiving more than 1.5 billion dollars in investment. The market is expanding, the legislation is becoming more conducive, while academic interest is increasing exponentially. The environmental, nutritional and functional benefits of insects as feed are becoming more and more recognized. Insects are poised to play an increasingly prominent role in shaping the future of animal feed production.

Keywords

animal feed – bait – insect pest

1 Introduction

In the Western world before 2010, there were several companies rearing insects as feed for birds, reptiles, and aquaria fish, providing them to hobbyists or zoos. The worldwide interest in farming insects either for food and feed surged after the publication by FAO of the book *Edible Insects*: *Future Prospects of Insects as Food and Feed*

Published with license by Koninklijke Brill BV | DOI: 10.1163/23524588-00001232

(Van Huis *et al.*, 2013). The likely reason for this sudden interest was that the atmosphere for promoting insects as food and feed had become much more conducive. Society started to realize that food systems need to be reconfigured in the face of climate change (Loboguerrero *et al.*, 2020) and circularity is an important part of these systems (Van Zanten *et al.*, 2023). Therefore, the use of insects in addressing environmental problems in food production attracted attention because insects are highly efficient in converting organic side streams (e.g. fruits, vegetables, and even manure) into insect biomass, contributing to a circular economy. In addition, the sustainability of high protein feed ingredients such as fishmeal and soybean meal, is being questioned, e.g. farming soy can involve deforestation, biodiversity loss, and the use of pesticides (Van Huis and Gasco, 2023). Insect ingredients are also a valuable source of nutrition for animals with many possible health benefits (Gasco *et al.*, 2021). At this moment, the industry of insects as feed is growing rapidly and billions of dollars are being invested. The black soldier fly (*Hermetia illucens*) is by far the most mass-produced species for feed and petfood, whereas another dipteran species that can be used is the common housefly (*Musca domestica*). Several mealworm (Tenebrionidae) species are also used as feed: the yellow mealworm (*Tenebrio molitor*), the lesser mealworm (*Alphitobius diaperinus*), and the superworm (*Zophobas morio*). Several orthopteran species can also be used, such as crickets or grasshoppers.

The question is, however: Were insects used as feed before the industry started to mass-rear them for this purpose? In the Western world, it was known that insects are used as bait for fishing. However, in tropical regions, insects were employed as feed in a traditional manner. This probably had to do with the indigenous knowledge of farmers about how to exploit the natural feeding behaviour of their production animals (Musundire *et al.*, 2021). Another motivation for smallholder farmers was the need to look for sustainable alternatives to the expensive imported feed ingredients, such as fishmeal and soybean meal. In most developing countries, 30-80% of the total poultry population is farmed by smallholder families, who cannot afford those costs (Mottet and Tempio, 2017).

This review deals with the use of insects as feed in common production animals (poultry, pigs, fish) and pets (dogs, cats). Pets are included considering that pet food is the largest market for insect protein, at least in 2020 (De Jong and Nikolik, 2021). The purpose of the article is to give an overview of the transition of insects from being part of the natural diet to becoming a part of industrial production for animal feed. The first part deals with animals that naturally use insects as feed. As insect pests are also consumed by production animals, the second part deals with how they can be controlled by feeding them to animals. The third part is about how insects can be used as bait for fish and chickens. The fourth part deals with the transition from traditional to industrial systems, often starting with manipulating the environment to increase the availability of insects.

Insects, natural diet for animals

Insects are natural food sources for many fish and poultry species. To a lesser extent insects are also a natural food for pigs, dogs and cats. Even for primates they are a natural food (Sutton, 1990). For instance, termites of the genus *Macrotermes* are consumed by gorillas and chimpanzees (Deblauwe and Janssens, 2008). In the Western world it has only been realized in the last two decades that humans can also eat insects, something that was already known and common practice in several tropical countries (Van Huis, 2018). The use of insects as human food is very well documented; however, the information on insects used as feed is scanty. We will deal with this limited information and start with insects being the natural diet for poultry, pigs, fish, dogs and cats.

Poultry

Among the animal groups, insects are consumed most by poultry species. Not surprisingly, as most avian species are insectivores and consume between 400 and 500 million tons yearly (Nyffeler *et al.*, 2018). Eighty percent of the birds breeding in Central Europe feed on insects at least temporarily and in North American 61% of the birds are primarily insectivorous, 28% were partially insectivorous, and only 11% were not insectivorous (Capinera, 2010, p. 126). Savory (1989) reviewed a number of studies about the percentage of invertebrate food in diets of wild chicks of 21 gallinaceous species. In the first two weeks of life, 16 species were recorded as eating 50-90% (and some studies even more than 90%) invertebrate food; in the second two weeks, eight species ate more than 50% and six species less than 10%; and in the second month of life, 15 species were recorded with less than 10%. Concerning the domestic fowl *Gallus gallus* (free roaming), the same author found percentages of 50-90 of invertebrate food during the first month and 10-50 in the second month. Protein (Heuser, 1941) and energy (Yang *et al.*, 2020) requirements seem to be proportionate to the rate of growth, but the amino acid composition also plays a role (He *et al.*, 2021).

Ravindran and Blair (1993) listed a large number of insect groups being used as poultry feed: grasshoppers, crickets, cockroaches, termites, silkworms, flies (larvae and pupae) and bees.

In free-range farming systems, chickens are allowed to forage freely in the backyard. The scratching and pecking of free-range chickens expose insects in the soil, litter and among plants. In Africa, 80% of poultry production is produced traditionally, which means that the animals gather their food in a free-roaming manner (Goromela *et al.*, 2006). As feed constitutes 60-70% of the total cost of production, attempts are made to reduce those costs (Thirumalaisamy *et al.*, 2016). In Bangladesh, small-scale family poultry systems also account for 80% of total poultry production (Huque, 1999). In this study, analysis from the crop and gizzard of laying hens showed that under these scavenging conditions phosphorus and protein were the most limiting nutrients. Rice grain, boiled rice and vegetable materials, as well as insects and earthworms were found in the crop. Another study in Bangladesh also studied the crop content of scavenging layers and broilers (Rashid *et al.*, 2004). In the crop they found grains, kitchen waste, vegetables and as animal protein, small snails, earthworms, ants, flies, and cockroaches. They also found that the feed was deficient in protein, phosphorus and calcium. Both studies conclude that supplementary feed will increase the performance but that the price is too high to make it profitable.

Pigs

Few herbivorous animals, such as hogs, deliberately feed on insects (Capinera, 2020, p. 114). Wild pigs mainly eat vegetative material (like roots), but they are omnivores and therefore also eat insects (Ditchkoff and Mayer, 2009). An analysis of the percentage volume of food items in stomachs of male and female boar in the three Brazilian ecoregions in 2015 and 2016 showed 3% (Cervo and Guadagnin, 2020). However, this figure can differ depending on the season: during the flooding and dry seasons in the Pantanal ecoregion for the same years these levels were 10% and 1%, respectively, with frequencies of occurrence of 70% and 13%, respectively.

Fish

Insects are also part of the natural diet of carnivorous and omnivorous fish, both in freshwater and marine habitats (Henry *et al.*, 2015). Most of the diet of juvenile salmon feeding in freshwater consists of invertebrates, either those drifting on the water surface, in the water, or from benthic invertebrates on the streambed surface (Johansen *et al.*, 2011).

According to Macadam and Stockan (2015) the contribution of aquatic insects to the diet of freshwater fish varies depending on the size of the body of water, fish species and size, and season. They list several studies showing that more than half of the diet of six predatory fish species consists of aquatic insects belonging to the orders Ephemeroptera, Diptera and Trichoptera.

Dogs and cats

Bosch and Swanson (2021) discuss the natural occurrence of insects in the diet of dogs and cats. The dog is a direct descendent of the grey wolf (*Canis lupus*), and the cat of the wildcat (*Felis silvestris*). Insects were present in 5 out of 50 described diets of wild wolves, but with negligible contributions. Plantinga *et al.* (2011) reviewed 27 studies on free-roaming feral cats showing that they are obligatory carnivores and that invertebrates constitute only 1-2% of their diet. Pearre and Maass (1998) estimated the consumed biomass of insects in 35 diets to be only 0.5%.

2 Insect pests as animal feed

The occurrence of locust plagues may be an incentive to use them as feed for chickens (Adeyemo *et al.*, 2008). While this is not an appropriate way to control the pest (Van Huis, 2021b), it is an opportunity to obtain a free feed source. However, it may pose a feed safety risk as locusts are commonly controlled by pesticides.

Can insect pests be controlled by using chickens (Clark and Gage, 1996)? An example is the Mormon cricket (*Anabrus simplex*), an agricultural pest in the USA, which is eaten by many bird species (La Rivers, 1941). Its potential as chicken feed was already mentioned in 1929 by Cowan (1929). Therefore, they can be harvested from nature and fed to broiler chicks as a high protein feed, improving performance compared to a corn-soybean meal (Defoliart *et al.*, 1982).

In China, ducks in the paddy fields prey on 12 orders of insects reducing important rice pests such as planthoppers (Delphacidae), stem borers (*Chilo suppressalis*), and leaf rollers (*Cnaphalocrocis medinalis*), while supporting their growth and survival (Teng *et al.*, 2016). They also fertilize the rice fields. Rice-duck integrated farming is practised in Japan, South Korea, Vietnam, Myanmar, Philippines, Malaysia, and southern China. Other benefits found in Vietnam are that the ducks need no housing, management or feed, and produce meat and eggs (Men *et al.*, 1999). Furthermore, it has been proposed to control grasshopper species by collecting them and then use as feed for poultry (Anand *et al.*, 2008).

In Australia the wingless grasshopper (*Phaulacridium vittatum*) is a pest in viticulture, agricultural crops, pastures and can be found almost everywhere (Khusro *et al.*, 2012). Birds, but also free-roaming chickens, can effectively control this pest. Harvesting the insects from natural habitats and feeding them to chickens was also considered an option.

Larvae of the lesser mealworm can carry a wide variety of poultry-specific and zoonotic viral, bacterial, and parasitic pathogens (Smith *et al.*, 2021). However, Despins and Axtell (1995) found that broiler chicks performed well when the consumption of beetles is small in relation to feed consumption. Other experiments with lesser mealworms on broilers have been conducted since, e.g. Van der Heide *et al.*, (2021).

Sayed *et al.* (2019) reported that soybean meal can be substituted by up to 50% in Japanese quail (*Coturnix japonica*) diets by meals of the African or Egyptian cotton leafworm (*Spodoptera littoralis*), a general feeder infesting several crops and vegetables, and the peach fruit fly, *Bactrocera zonata*, an insect pest of a wide range of fruits and vegetables. The authors suggested that these two insect pests can either be collected or reared on food residues, using the knowledge and experience acquired during mass-rearing for the application of the sterile insect technique. The Egyptian cotton leafworm can also replace fishmeal for about 50% in the diet of Nile tilapia (Amer *et al.*, 2021)

Oyegoke *et al.* (2006) evaluated the replacement of fishmeal in broiler chick diets by meal from caterpillars of the pallid emperor moth or shea defoliator, *Cirina butyrospermi*, a pest known to defoliate shea trees (*Vitellaria paradoxa*), an economically important tree species in the savanna region. The authors reported no negative effect on the performance and growth of chicks fed entirely or partly with the caterpillar meal compared with fishmeal. Similar results have been reported in Nigeria with up to 75% replacement of fishmeal with the silkworm *Cirina forda* meal in laying hen diets without effects on feed intake, weight gain, egg production, feed efficiency or egg quality characteristics (Amao *et al.*, 2010).

Meal from larvae of the silkworm *Anaphe venata*, a pest of the tree species *Triplochiton scleroxylon* that is used commercially for timber, has also been used as a substitute for fishmeal in broiler chicken feed in Nigeria, without adverse effect on feed intake, body weight gain, feed conversion and protein efficiency ratio compared to the conventional fishmeal diet (Ijaiya and Eko, 2009). Additionally, the caterpillar meal was more cost effective than the conventional fishmeal.

3 Insects as bait

In the realm of angling and fishing, the use of insects as bait has long been standard practice, and many insect species, such as ants, grubs, grasshoppers, nymphs (Plecoptera), crickets, and caterpillars are ideal for use as live freshwater fishing bait for catching many fish species (McCafferty and Provonsha, 1998).

In Africa, termites caught in the wild are used to catch fish and birds. Silow (1983) reported the use of snouted termites (*Trinervitermes* spp.) in Zambia as fish bait in conical reed traps and as bait to attract insectivorous birds (such as guinea fowl, francolins, quails and thrushes). The birds were caught by setting a snare across the broken top of a termite mound, where soldiers amass for hours, a practice also known from Congo. Fishermen in Chad and the Democratic Republic of Congo also use termite larvae as bait (Van Huis, 2017b). In Tanzania the larvae of Melolonthinae and Tenebrionidae are used for fishing (Van Huis, 2021a).

In South America, insects are frequently used as bait by fishermen. Dufour (1987) mentioned that female alates of termites (*Syntermes* sp.) and a small caterpillar, were collected in the Northwest of the Amazon as fishing bait. Ruddle (1973) reported the use by Amerindian ethnic groups from Colombia and Venezuela of unidentified ants to catch sardines and dorado (*Salminus brasiliensis*). In the artificial lake of Paranoá in Brazil, fishermen used as bait black soldier fly larvae, known as 'boro'. The rearing and marketing of the fly became a local economic activity (Santos and Coimbra, 1984).

Many species of insects (both wild and reared) are used as bait for freshwater fish in North America (Peterson, 1956; McCafferty and Provonsha, 1998). In the early 1990s, a study of the bait industry in the USA was carried out, analysing data from one thousand retailers and wholesalers (Copes and Meronek, 1995; Meronek *et al.*, 1997). The most valuable insect baits, in descending order of sales, were: 'grubs' (i.e. larvae of the dipterans as 'spikes' *Calliphora* sp., or 'mousies' *Eristalis* sp.); 'waxes' (i.e. larvae of the lepidopteran *Galleria mellonella*); and may fly larvae (*Hexagenia* spp.). Smaller quantities of crickets (*Gryllus* spp.), hellgrammites or dobsonfly larvae (Corydalidae) and dragonfly larvae (Aeshnidae, Libellulidae and Corduliidae) were also sold. The wholesalers reported that about half (54%) of their non-fish bait was harvested from the wild and almost half (46%) was farmed, but this varied widely between states. Wholesalers reported that 100% of hellgrammites and mayflies were harvested from the wild, whereas larvae of waxworms (*G. mellonella*) and maggots of hoverflies and *Calliphora vicina* were reported to be more commonly reared than harvested from the wild (85%) (Meronek *et al.*, 1997). The larvae of drone flies (Syrphidae: tribe Eristalini) are preferred for certain types of specialist fishing, such as ice fishing (Hollingsworth, 1967). There was also a commercial fish bait production of the black soldier fly in the USA prior to the current highly industrial mass production of this species as feed (Booth and Sheppard, 1984).

In Europe, a wide variety of insect baits have been traditionally used for freshwater fishing (Ronalds, 1836), including mainly aquatic adult insects such as stoneflies (Perlidae), caddisflies (Trichoptera), mayflies (Ephemeridae), alderflies (Sialidae), etc., but also terrestrial insects such as flies, beetles, ants, etc. However, the most frequently used insect baits today, i.e. housefly larvae, and larvae of green bottle and blue bottle fly larvae (both Calliphoridae), were not widely used until the early twentieth century when massive rearing was started by Arthur E. Bryan, 'The Maggot King' in the United Kingdom, (Thompson, 1956; Wainwright *et al.*, 2007).

Unfortunately, the widespread use of mass-produced insect larval baits has caused allergic reactions in some anglers. Since the 1970s, baits containing larvae of mainly blow flies (Caliphoridae), but also housefly larvae, have been found to cause this reaction (Buisseret, 1978). Stockey *et al.* (1982) studied the first case associated with blue bottle flies, and Sestini and Innocenti (1987) mentioned that larvae of *Calliphora erythrocephala* (actually *Calliphora vicina*) are also related. The same problem occurred when yellow mealworm and other insects were used as bait (Bernstein *et al.*, 1983; Siracusa *et al.*, 1994). This was also the case for larvae of *Protophormia terraenovae*, a blue bottle fly species recently introduced as commercial fish bait (Porcel Carreño *et al.*, 2009).

It is interesting to highlight that early experiments to assess the role of insect biomass in aquaculture started with aerial insects in the adult stage, which were attracted by light over fishponds (Heidinger, 1971; Merkowsky *et al.*, 1977). In addition, the use of night lighting also concentrates the number of aquatic insects and zooplankton in a pond (Graves and Morrow, 1988), partially avoiding additional feed supplementation and consequently improving water quality (Harder and Gotsch, 2007; Mischke *et al.*, 2011). Most studies on the 'attractor effect' of night lighting and fish feeding have been conducted in North America, but more recently some have been conducted in South Africa (Rapatsa and Moyo, 2017). Both nocturnal fish species such, as *Ictalurus punctatus*, *Sander vitreus* or *Clarias gariepinus*, and diurnal species, such as *Oreochromis mossambicus* have been investigated. Rapatsa and Moyo (2017) indicated that the insect groups eaten by the last two species in South Africa were mainly moths and beetles. The adult insects obtained had lower protein levels than fishmeal and their numbers were low, therefore not supporting optimal growth, particularly in winter. However, it was still cheaper than fishmeal.

In several sub-Saharan countries, grasshoppers, such as *Zonocerus* species (*Z. variegatus* and *Z. elegans*), are used as bait for fishing. As such they may be sold to fishermen. Several orthopteran species are also used for fishing, such as the desert locust and the mole cricket *Gryllotalpa africana*, but the wings must be removed otherwise they float (Van Huis, 2022).

In Thailand, earthworms, yellow mealworms, termites, burrowing cockroaches (*Pycnoscelus indicus*), diving beetles (*Cybister limbatus*), and the nymphs of the American cockroach (*Periplaneta americana*) are commonly used as bait to attract fish. These baits are offered both alive and frozen forms at fish bait shops (Attawit Kovitvadhi, personal communication).

There is a long history of imitating aquatic insects to catch fish. The sport and technique of fly-fishing does just this, mimicking the appearance and behaviour of mayflies and other insects used naturally as prey. The earliest reference to the use of artificial flies was made by a Roman poet at the beginning of the first century AD (Radclife, 1921). While the societal benefits of aquatic insect diversity in recreational fishing are clear (Morse, 2017), there are also economic benefits as mentioned by Macadam and Stockan (2015). The authors report that in Scotland the capture of Salmonid fish by fly fishing is estimated to be worth £112 million annually, while in the USA 25.4 million people are involved in freshwater fishing worth US $31.4 billion, which rely entirely on freshwater invertebrates.

Even birds can use insects as bait for fishing. Several species of herons (Ardeidae) and other water birds around the world catch fish by picking up insects and dropping them at deliberately chosen places in the water (Ruxton and Hansell, 2011; Réglade *et al.*, 2015; Jelbert, 2021).

4 Insects traditionally used as feed

In West Africa, feed represents up to 70% of total production costs (Omole *et al.*, 2005). High protein feed ingredients (fishmeal and soybean meal) are unaffordable for smallholder farmers and fish producers, so for many rural farmers in developing countries insects are a low-cost and readily available source of supplemental feed for poultry and fish. How do farmers all over the world traditionally procure insects for their production animals?

For edible insects for human consumption a number of simple production systems are available (Van Huis, 2017a). However, for insects as feed there is much less information available, and what there is, mostly deals with feed for chickens.

We will discuss how different insect groups are used traditionally as feed. These groups are caterpillars, crickets and grasshoppers, termites, cockroaches and flies. They are either already in use by farmers or have been tested in experiments by researchers.

All insect groups

In Southeast Asia, fluorescent lights are suspended above fish ponds to attract insects, which because of the light reflection in the water fall into the pond where fish eat them (Anonymous, 2019). During a trip in Lao People's Democratic Republic the main author observed a light trap facing rice fields. The owner explained that each morning he selected from the catch the insects that could be consumed by the family, and the rest was given to the chicks.

Night-time lighting not only attracts terrestrial insects which can then be used as natural feed for pond fish but it also concentrates the number of aquatic insects in a pond which can then serve as food for fish (Rapatsa and Moyo, 2017). The species that have been investigated are nocturnal such as *Ictalurus punctatus*, *Sander vitreus* and *Clarias gariepinus*, and diurnal such as *Oreochromis mossambicus*. Rapatsa and Moyo (2017) found that the last two species mainly eat moths and beetles in South Africa. The adult insects have lower protein levels than fishmeal and their numbers were low, therefore not supporting optimal growth, particularly in winter. However, it was still cheaper than fishmeal. Another advantage of the method is that the water quality does not deteriorate, as is the case when using fishmeal.

The possible application of aquatic insects from a sewage lagoon was suggested as early as 1972 (Schurr, 1972). Williams *et al.* (2021) reviewed the available information on the use of aquatic insects of different orders, e.g. Ephemeroptera, Odonata or Trichoptera, for food and feed applications, as well as the existing protocols for their harvesting. According to the authors their potential as a nutrient source is considerable, although the current use of most aquatic insect species is limited.

Incorporating the full fat meal of house crickets (*Acheta domesticus*) and mulberry silkworm pupae (*Bombyx mori*) at 20% and 14%, respectively, into dog diets did not demonstrate any adverse effects on safety, blood parameters, or faecal microbiota (Areerat *et al.*, 2021, 2023). Consequently, commercial products containing these novel proteins have been introduced in several countries. These protein sources are considered to have a lower likelihood of triggering food allergies compared to conventional protein sources, making them viable options for hypoallergenic diets for both cats and dogs.

Lepidoptera

In West Africa, the shea caterpillar has often been studied as an ingredient in chicken or fish feed (Hien *et al.*, 2010; *Anvo et al.*, 2017; Seidu *et al.*, 2024). Several caterpillars or pupae of lepidopteran species were tested in Nigeria as a replacement for the commonly used expensive fishmeal in chicken feed. The silkworms *C. forda* (Oyegoke *et al.*, 2006) and *Anaphe infracta* (Ijaiya and Eko, 2009) were suitable for broilers and the latter species also for layers (Amao *et al.*, 2010). In Botswana the mopane caterpillar (*Gonimbrasia belina*) can partially or completely replace fishmeal in poultry diets, but the seasonality is a problem (Moreki *et al.*, 2012). All these insect species are also used as human food.

Mulberry and non-mulberry silkworm pupae are a major by-product of silk production: for each one kg of raw silk, 8 kg of wet pupae (2 kg of dry pupae) are produced (Sheikh *et al.*, 2018). Discarded pupae are an environmental concern. So, why not use silkworm pupae meal a protein-rich feed ingredient with a high nutritional value? This also takes into consideration that prices of soybean meal and fishmeal are high. In many countries (Bangladesh, Brazil, China, India, Pakistan and Thailand) experiments have been done using the pupae for broilers, layers, pigs and fish. According to Fagoonee (1983) 50% of fishmeal could be replaced with ground spent silkworm pupae with no adverse effect on broiler chicks, but higher inclusion levels reduced consumption. Joshi *et al.* (1980) replaced 75% iso-nitrogenously of fishmeal with defatted silkworm pupae meal without affecting the egg production of layers.

The pupae of the Eri silkworm *Samia ricini* are not eaten in Nepal, but considered as feed for poultry and pond fish (DeFoliart, 1995). In contrast, while Eri silkworm pupae are consumed by humans in Thailand, the taste of mulberry silkworm pupae is preferred. Consequently, *S. ricini* silkworm pupae are used as feed for broilers on small-scale farms, comprising up to 15% of the diet without any reported adverse effects. This dietary inclusion has also been associated with an enhancement in the yellow colour of the broilers' skin (Kongsup *et al.*, 2023). Also, the caterpillar frass and rearing residue can be used for pond fish culture. For example, in India, commercial sericulture activities generate a lot of waste, consisting of leftover leaves, soft twigs and silkworm excreta. This is normally used to make compost and biogas, but Krishnan *et al.* (2011) dried the sericulture waste and ground it to a powder with a protein content of about 17%. This was fed to poultry improving their feed conversion ratio, with a similar feed intake and hence a higher body weight compared to poultry fed the control diet.

Orthoptera

In India, four acridid species were suggested as poultry feed (Anand *et al.*, 2008) either by collecting them or by farming them. Locust plagues are an opportunity for using the insects as feed. *Locusta migratoria* has been proposed to replace up to 25% of fishmeal for juvenile Nile tilapia, *Oreochromis niloticus* (Abanikannda, 2012; Emehinaiye, 2012), whereas for fingerlings of the same fish species good results have been reported for the partial replacement of fishmeal with meal of unspecified grasshoppers (Okoye and Nnaji, 2005). Similarly, the integration of grasshopper meal into diets of the African catfish, *Clarias gariepinus*, shows promise, either for unspecified grasshoppers (Nnaji and Okoye, 2005) or for the variegated grasshopper, *Zonocerus variegatus* (Alegbeleye *et al.*, 2012). House crickets also appear to be a good ingredient for chickens (Nakagaki *et al.*, 1987).

Contradicting results have been reported for the inclusion of field-collected grasshopper meal in broiler diets, as they have been shown to suppress weight gain and feed efficiency of broilers (Ojewola *et al.*, 2003) or efficiently support broiler growth and performance (Ojewola *et al.*, 2005). However, these differences might be due to the various species and developmental stages of the collected grasshoppers that may have subsequently affected the nutritional composition of the grasshopper meals.

***Blattodea* (termites)**

Termites have been traditionally used in African countries as poultry feed (Boafo *et al.*, 2019; Boko *et al.*, 2012; Deng *et al.*, 2024; Hien *et al.*, 2005; Sankara *et al.*, 2018; Vorsters *et al.*, 1994). In general, more than 40 termite species belonging to four families have been reported for food or feed applications (Figueirêdo *et al.*, 2015).

Chickens or guinea fowls do not have direct access to termites, which are protected by the termite mound. So, in several sub-Saharan African countries, farmers break up small termite nests (*Microtermes* spp.) or parts of termite mounds to feed the chickens or chicks (Van Huis, 2017b). The termite species used most are those of the genera *Cubitermis* and *Pseudoacanthotermes*. According to Diawara (2013), cited by Pomalégni *et al.* (2017), this practice is very common, with 72% of the farmers in South-Western Burkina Faso using termites to feed poultry.

The results of a recent survey in Burkina Faso among 1100 poultry farmers revealed that almost 80% of them still use termites, at least occasionally, to cover their domestic poultry's nutritional needs (Sankara *et al.*, 2018), the most commonly used being the large, winged *Macrotermes*. Similar results are also reported for Ghana (Boafo *et al.*, 2019).

Collecting termites directly by breaking their mounds destroys the termite nests and may negatively affect the African ecosystems. Trapping them in containers filled with organic substrates as attractants can be a more sustainable alternative (Boafo *et al.*, 2019; Dao *et al.*, 2020). The method consists of putting dry stems of sorghum or other cereals, such as dried maize cobs, in a clay pot (Farina *et al.*, 1991; Riise *et al.*, 2004; Sanchez, 1996). Water is added and the clay pot is turned upside down with the opening on a termite gallery. The microclimate within the pot is ideal for termites. After one to two days, the number of termites is considerable, and the pot is emptied for the chicks. However, the number trapped is highly influenced by the type of container, the substrate, the season, the habitat, the harvesting times and the duration of trap deposition (Dao *et al.*, 2022). Dao *et al.* (2020) recently reviewed the techniques of harvesting termites in Burkina Faso, and reported that at least five termite species are locally used in traditional poultry farming. More specifically, it was stated that species of the genera *Odontotermes*, *Trinervitermes* and *Macrotermes* are commonly fed to chickens and guinea fowls, whereas a *Cubitermes* species is sometimes used to feed guinea fowls (Dao *et al.*, 2020). The same termite genera (*Macrotermes*, *Trinervitermes* and *Odontotermes*) have also been reported to be commonly used in Ghana (Boafo *et al*., 2019).

Although *Odontotermes* termites can apparently be provided to poultry *ad libitum* without adverse effect, termites of the genus *Macrotermes* are recommended to be fed to chicks older than one month, as soldiers can bite and hurt chick throats. Toxicity concerns (likely due to the diterpenes and monoterpenes that are released from their snout to deter ants and predators) have been raised for species of the genera *Trinervitermes* and *Cubitermes*, especially when fed in excess (Boafo *et al*., 2019; Dao *et al*., 2020).

Termite meal can also be used. A very detailed description of using termites for poultry (chickens, ducks, and guinea fowls) in many parts of Africa is given by Iroko (1996, pp. 113-118). This concerns both methods: (1) cutting small termite hills and breaking them in the compound where poultry is held (e.g. by using ash sprinkled on the termites to prevent them escaping from their dismantled nest); (2) the capture of termites in pots as mentioned above. To reduce the cost of chicken feed, Munyuli Bin Mushambanyi (2002) in the Democratic Republic of Congo collected termites (*Kalotermes flavicollis*) and cockroaches (*Blatta orientalis*), both considered harmful for agriculture and public health, respectively; these insects were then dried and ground, and given to broilers.

In East and southern Africa, some farmers feed their fish termites, which are either collected by the farmer or purchased from collectors throughout the year (Rutaisire, 2007). The quantity obtained depends on the number and size of termite hills on the farm. On average, a termite hill yields approximately 50 kg per annum. Besides raw or dried termites, locusts, fly maggots and silkworm larvae are fed to trout, tilapia, catfish and carp.

Replacing fishmeal with meal from termite meal from oven-dried reproductive adults of *Macrotermes subhyalinus*, improved growth and performance in fingerlings of *Heterobranchus longifilis*, a commonly cultured catfish in Nigeria (Sogbesan and Ugwumba, 2008), the best results being acquired with the 50% replacement, suggesting the termites are complementary to the fishmeal.

Diptera

The Network for Smallholder Poultry Development produced a manual for rural poultry farmers worldwide dealing with improved free-range systems consisting of small flocks of 5-50 local or cross-bred chickens (Riise *et al*., 2004). In these systems, many birds die very young, due to predators, disease, starvation, adverse weather conditions, and accidents. Among other things, the manual provides information on the best time for chickens to scavenge to procure most insects: early morning and late afternoon. They can be supplemented by providing maggots and termites as a cheap source of a number of critical nutrients including trace minerals, many vitamins and energy in addition to their value as a protein supplement. These should be given to the small chicks, as they have the greatest need for a good protein source. The maggots of flies (mainly houseflies) can be obtained by the following rearing method: mixing blood, offal, and cow manure in a large open pot, filled with one third of water, and left open during the day so flies can oviposit and closed during the night. After 5-10 days (depending on temperature), the maggots can be collected by pouring water into the pot so that they float and can be scooped off and fed to the birds.

Nzamujo (1999) describes a similar approach with naturally exposed substrates to produce maggots in Benin. Briefly, organic substrates (animal manure or offal, rumen content, brewery waste, decaying fruits, etc.) are placed on rearing beds on the soil to serve as oviposition substrate. After some days, the substrate is sieved to collect the maggots that are then fed to livestock animals, e.g. poultry, or fish, fresh or sun dried. The productivity of this system greatly depends on the substrate and the season; however, it is suggested that 3 to 4 kg of live maggots can be produced in 4 days using 10-15 kg of dry matter substrate in $1 \times 1 \times 0.1$ m beds.

Cow and goat blood from a Nigerian slaughterhouse mixed with wheat bran, rice dust and saw dust were also used as attractant for flies (Aniebo *et al*., 2008). Mixtures of 25 kg blood and 5 kg wheat bran yield around 7 kg of fresh maggots Among the different animal and vegetal substrates that have been tested as attractants for flies in Côte d'Ivoire, animal offal attracts more flies for oviposition and subsequently produces many more larvae than fermented plant substrates (Bouafou *et al*., 2006). In Cameroon, the exposure of cow dung and chicken manure to flies for maggot production showed that the latter was more efficient (Mpoame *et al*., 2004).

In Ghana and Burkina Faso, fresh housefly larvae are collected from chicken manure and fed to chickens. Téguia *et al*. (2002) also collected housefly larvae from a commercial layer farm, but dried and milled them and fed them to chickens. He concluded that broilers performed well on maggot meal. Similarly, Dankwa *et al*. (2002) supplemented the diet of scavenging chickens with live housefly larvae and observed an overall improvement in the birds' performance in terms of egg production and growth.

A recent survey in Burkina Faso among 360 traditional poultry farmers showed that almost 15% of the respondents use fly larvae, mainly of the housefly but also of the black soldier fly, collected after exposure of organic substrates to naturally occurring adult flies, for poultry nutrition (Sanou *et al.*, 2018).

Calvert *et al.* (1970) did an experiment with the aim of solving the problem of poultry waste disposal. They used the housefly in a simple rearing system to produce a fertilizer and at the same time a high protein feed supplement in the form of dried fly pupae for chickens (Calvert *et al.*, 1969). This is probably one of the first publications on biotransformation of waste (manure) to high-quality proteins. The first studies that dealt with the black soldier fly converting manure to feed for pigs were by Newton *et al.* (1977) and for poultry by Hale (1973).

Kenis *et al.* (2014) identified the challenges in successfully implementing small-scale production systems of maggots that could be adopted by smallholder farmers in developing countries. These are mainly the selection of efficient and cost-effective substrates, the enhancement of oviposition, egg collection and larval extraction, as well as their drying and storing, and safety issues related to human and animal diseases.

An open system has been established and successfully evaluated in western Kenya for attracting and 'farming' wild black soldier fly larvae, which can provide local, small-scale farmers with a valuable source of protein for poultry and fish production and efficiently valorise locally available organic waste substrates of plant and animal origin (Nyakeri *et al.*, 2017).

In Guinea, black soldier fly larvae obtained from natural oviposition on fermented palm kernel meal in open tanks were fed to tilapias with satisfactory results, however this production system was vulnerable to the fluctuations in natural oviposition (Hem *et al.*, 2008). In Nigeria, the hybrid catfish *Heteoclarias* performed best (yield and profitability) when fed with a 25% inclusion of housefly maggot meal diet (Sogbesan *et al.*, 2006).

In Hong Kong, several *Chironomus* spp. (Diptera: Chironomidae) are grown on chicken manure, providing a nutrient source for aquarium and carnivorous fish in fish culture, as well as a means for poultry manure management (Shaw and Mark, 1980).

Other aquatic Diptera, e.g. Simuliidae, Culicidae or Chaoboridae, have also been proposed as feed for livestock after being collected from the wild; however, their potential still needs to be tapped (Williams *et al.*, 2021).

In Thailand, there is growing interest in the use of black soldier flies for small-scale fish, poultry, and pig farming to promote a circular economy. The insects are attracted to their living areas using fermented pineapple peels; fermented spent coffee grounds can also be used (Khaekratoke *et al.*, 2022). Organic waste from markets is also repurposed as feed for black soldier flies.

***Blattodea* (cockroaches)**

The meal of American cockroach nymphs (*P. americana*) has been used as feed for juveniles of the Japanese carp (*Carassius auratus*) (Hernández-Martínez *et al.*, 2008). Powder of the same cockroach could replace conventional protein sources for Japanese quail (*Coturnix japonica*) (Al-Salhie *et al.*, 2021). It is also used as feed in China, where the insect is reared for medical applications (Feng *et al.*, 2018).

Hymenoptera

In Canada close to 2 billion kg of honeybees (*Apis mellifera*) are killed after the honey-producing season. However, they can be dried into meal and incorporated (150 g/kg) in diets of growing turkeys (Salmon and Szabot, 1981). Nutritive value and extraction methods are given by respecitively, Ryan *et al.* (1983) and Qzimek (1985).

5 The first steps to industrialization

In this section, the developments from traditional to industrial systems is reviewed for the different animal groups, chickens, pigs, fish, dogs and cats.

Chicken

Houseflies in manure have long been controlled with pesticides (Breeden *et al.*, 1975). But it is also possible to use a system in which the manure is used to collect housefly maggots and feed them to poultry. Another way is to use the black soldier fly which lowers housefly populations in competition (Miranda *et al.*, 2019).

According to a survey in Benin, approximately 6% of farmers produce housefly larvae to feed their flocks; this rose to 25% in some departments (Pomalégni *et al.*, 2017). These farmers are often highly educated, have larger flocks which are kept inside and have an above average income. Larvae are obtained by leaving substrates such as soy and maize bran, and pig and chicken manure exposed in containers to attract naturally occurring flies. This is a simple method for smallholder African farmers as it only involves exposing the substrates, from which the larvae can be extracted a few days later. Koné *et al.* (2017) give recommendations to scale up this production, by for instance using trays in stacked shelves.

A very cheap method is practised by poultry producers in the KwaZulu-Natal Midlands in South Africa to partly replace expensive chicken feed with homegrown, live maggots (Joubert, 2012). They use a system of two stacked buckets. A layer of chicken litter topped with chicken offal is placed in the top bucket. Naturally occurring flies enter the top bucket and lay eggs. The maggots eat the offal, and when they are fully grown, they burrow through the chicken litter and fall through the fabricated holes into the bucket below. Then the maggots are fed live to the chickens.

Insect production and use for poultry feed was already reported back in the 1970s. The ability of the housefly to bio-convert organic wastes such as manure from chickens or pigs as well as municipal organic waste was put to good use. The meal of the obtained larvae or pupae meals were included in poultry feeds. The results were equal to or better than those of diets used as controls, which contained conventional protein sources (soybean meal, meat and bone meals, or fishmeal) (Calvert *et al.*, 1969; Calvert *et al.*, 1970; Miller *et al.*, 1974; Ocio *et al.*, 1979; Papp, 1975; Teotia and Miller, 1973, 1974). An overview of the use of housefly maggots for poultry and rodents is also provided by Ekonda (2012).

From India Dhaliwal *et al.* (1981) reported feeding broilers by replacing fishmeal at ratios of 50 and 100% with dry housefly pupae meal; the weight gain was 3% and 21% less, respectively, compared to the control (without replacement). From Slovakia Chrappa *et al.* (1990) showed that 3-5% of a commercial feed mixture can be replaced with poultry excreta bioconverted by housefly larvae (containing excreta and pupae) for broiler chicks.

A more industrial method for converting poultry waste into a high-protein feedstuff is mentioned by El Boushy (1991). He proposed to convert manure from caged layers with houseflies to produce housefly-pupa meal. By adding a building to layer houses, it is possible to continuously produce upgraded manure composed of pupa mixed with manure residues. This can be treated by heating it up to 180 °C for sterilization, and then drying it for use as a well-balanced protein source.

Ramos-Elorduy *et al.* (2002) used the yellow mealworm, grown on several dried waste materials from plant origins, as feed for broilers. Inclusion levels up to 10% in a sorghum-soybean meal basal diet for 15 days showed the potential of yellow mealworms as a protein source for broilers.

Since then, many experiments have been conducted. Dörper *et al.* (2021) reviewed about 30 studies, most published after 2015, indicating inclusion levels of black soldier fly and housefly products in diets of broilers, laying hens, ducks and quails and their effect on digestibility, performance, product quality, and animal health in diets that are isonitrogenous and isocaloric. The review concludes that partial replacement of fishmeal or soybean meal by fly larvae in feed is beneficial for poultry. The challenges are to determine whether the provision of live larvae can enhance poultry welfare, because of increased foraging by the animals. However, it remains to be seen what the optimal inclusion levels are and to identify potential functional properties of insect-based feeds.

The lesser mealworm was first considered a common insect pest for poultry; however, the perspective has changed, and it is now seen as a potential nutrient source, in particular for aquaculture (Rumbos *et al.*, 2018). Now, mostly the yellow, but also the superworm is used as feed for poultry, pigs, fish and pets (Rumbos and Athanassiou, 2023).

Pigs

One of the first studies dealing with insects fed to pigs was conducted by Newton *et al.* (1977). He obtained black soldier fly larvae from cattle faeces and urine slurry, dried and ground them, and compared them to soybean meal in pig feed. The larvae meal was acceptable to the pigs. After that, various studies evaluated the use of insects as pig feed. Hong and Kim (2022) listed 21 publications between 2000 and 2021 with most being very recent (last five years). These included experiments with various insect species (black soldier fly, housefly, mealworms) conducted in various countries. Nutritional values appeared to be adequate, but establishing optimal levels of inclusion and determining functional properties is challenging. Lestingi (2024) mentions the high non-competitive production costs, also mentioned by Veldkamp and Bosch (2015). Considering inclusion levels for pigs, Veldkamp and Vernooij (2021) indicated that the protein content of the insect species is largely comparable to soybean meal, but lower than fishmeal, while the amino acid profile is similar to both. Depending on the pig breed and age, and insect species, inclusion levels between 2 and 10% did not affect performance, although inclusion levels up to 100% are reported (DiGiacomo and Leury, 2019). Also, Lestingi (2024) concluded in a review article that up to 10% inclusion of black soldier fly and yellow mealworm can be used in growing pig diets without affecting growth performance and nutrient digestibility. However, as the fat content of insects is higher than soybean meal and fishmeal, either a defatting step is required, or the dietary inclusion level should be limited.

Fish

One of the first studies of using the black soldier fly and housefly as feed ingredient for fish (rainbow trout) was carried out by St-Hilaire (2007). Henry *et al.* (2015) reviewed the history of incorporating insects in fish feed for herbivorous/omnivorous fish species, i.e. catfish, tilapia and carp. The insect species mentioned are Diptera (black soldier fly and housefly), Coleoptera [different mealworm species, palm weevils (*Rhynchophorus* spp.) and *Oryctes rhinoceros*], Orthoptera (locusts, grasshoppers, crickets), Blattodea (termites), and Lepidoptera (silkworm meal) as a replacement for fishmeal and fish oil in the diets of fish and crustaceans (Henry *et al.*, 2015; Makkar *et al.*, 2014; Riddick, 2014; Tran *et al.*, 2015). According to Henry *et al.* (2015), most early studies were conducted in Asia and Africa because the fishmeal was of low quality. Another likely reason is that the farmers could not afford the high price of commercially produced feed. Those early studies did not use insect meal but whole or ground insects. Liland *et al.* (2021) reviewed the literature using 35 aquatic species and 14 insect species looking at dietary composition and performance outputs. They indicated that 25-30% replacement of fishmeal is possible while higher inclusion levels reduced protein digestibility, unbalanced the amino acid profile and increased the levels of saturated fatty acids. However, Nairuti *et al.* (2022), when reviewing the replacement levels of fishmeal with black soldier fly, mentioned that this depends on the fish species, e.g. for Atlantic salmon 100% of fishmeal can be replaced by insect ingredients (Gasco *et al.*, 2023a). It is expected that the insect market for aquaculture will increase almost tenfold in the coming decade. It will probably be about 40% of the insect market in 2030, and about 1% of the global aquafeed market (De Jong and Nikolik, 2021). As insects are a natural food for various fish species, their use as feed would seem logical.

Dogs and cats

In a screening study of the use of insects as feed for dogs and cats, eight species were used: housefly pupae, house crickets, black soldier fly larvae and pupae, yellow mealworms, lesser mealworms, superworms, six spotted roaches (*Eublaberus distanti*), death's head cockroaches (*Blaberus craniifer*), and Argentinean cockroaches (*Blaptica dubia*) (Bosch *et al.*, 2014). The protein content and amino acid scores, as well as *in vitro* organic matter and nitrogen digestibility varied considerably between insect substrates. Pupae of the housefly and black soldier fly had particularly good amino acid scores, while their nitrogen digestibility was lower than conventional protein sources in these *in vitro* studies. In contrast, the three mealworm species were lower in protein content and amino acid scores but had a high nitrogen digestibility.

In many countries there are no legislative restrictions for using insect-based ingredients in pet food because pets are not consumed by humans. Four insect groups are currently used as feed for pets: black soldier fly larvae, mealworms, silkworm pupae and crickets. There is an increasing number of companies that are bringing insect-based dry feed and treats for pets on the market (Valdés *et al.*, 2022). In the beginning companies were hesitant because they were aware that pets (dogs and cats) are often considered members of the family. Pet owners who have a strong aversion to insects are also unlikely to consider insect-based food for their pets (Kępińska-Pacelik and Biel, 2022). However, despite the first limiting in specific amino acids like methionine (with the caveat that they also contain high levels of choline which can spare the need for this amino acid), threonine, or leucine, depending on the insect species and whether it is for cats or dogs (Bosch and Swanson, 2021), insects are nutritionally adequate. Furthermore, in general, industrially produced insect-based pet food is considered safe and may have health-promoting effects (Siddiqui *et al.*, 2023). Research is ongoing to assess the digestibility of different insects in (dog) pet foods, and their impact on gut health and microbiota (Abd El-Wahab *et al.*, 2021; Lisenko *et al.*, 2023). Pet food was the largest market for the insect industry in 2020 and is expected to increase more than two times by 2030, although the total market contribution will diminish from more than 50 to 30% (De Jong and Nikolik, 2021). The growing interest is because owners are willing to give their pets high-value expensive products that are sustainable and may be hypoallergenic.

6 Discussion and conclusions

The main disadvantages of collecting insects from nature are: (1) the unpredictability of harvest due to seasonality associated with abundance; (2) variation in their nutritional value; (3) inability to guarantee feed safety; and (4) unsustainability of a production chain based on harvesting from nature. The only way to control these variables is to farm the insects. Also, Khusro *et al.* (2012) warns about using live insects as feed as they are difficult to handle, are incompatible with current automated feeding systems and have the potential to act as vectors in the transmission of bacterial and viral diseases. Processed insect feed simplifies handling, automated feeding and storage. Nyangena *et al.* (2020) recently reviewed the traditional processing techniques commonly used in East Africa, i.e. boiling, toasting, solar-drying, oven-drying, and discussed their effect on the proximate composition and microbiological safety of several collected or reared insect species utilized for both food and feed applications.

When insects are traditionally used it is often a supplement to an existing diet, either being commercial or part of a scavenging diet of free ranging animals. In a more industrial context, the diet is more controlled, and insects are used to balance the nutrients for the target animal. However, this is a challenge as for example, black soldier fly larvae can be reared on many different waste streams (Surendra *et al.*, 2020), the reason that Deruytter *et al.* (2023) called for standardized research protocols enabling to compare different studies and understand better the effects of different variables.

Another advantage of using insects in monogastric animal diets is that they may have health-promoting effects (Biasato *et al.*, 2023; Van Huis and Gasco, 2023). Veldkamp *et al.* (2022) mention three categories of bioactive compounds: (1) antimicrobial peptides which disrupt the bacterial membrane and for which it is difficult to develop resistance; (2) fatty acids (especially lauric acid with antimicrobial action of which BSF fat has high concentrations); (3) chitin, present in the exoskeleton of insects with immuno-modulating, prebiotic and microbiota-modulating effects. These compounds may contribute to reducing antibiotic use and prevent antibiotic resistance in livestock.

In many of the early publications the effects of chitin are questioned. Its function as a dietary fibre has been suggested, but there are others authors who claim that it can decrease the digestibility of other compounds such as proteins (Oonincx and Finke, 2023). Indeed, protein digestibility can be lower for proteins that are sclerotized with chitin. However, this negative effect seems to be offset by the beneficial properties of chitin and its derivatives. Chitin can activate the innate immune function in mammals (Shibata *et al.*, 1997; Suzuki and Park, 2018), and certain fish (Esteban *et al.*, 2001). While chitin can be effective, chitosan and chitin oligosaccharides often seem more effective (Esteban *et al.*, 2001; Harikrishnan *et al.*, 2012). The inclusion of chitin and its derivatives in aquafeed seems to enhance lysozyme activity, and thereby protect against bacteria, viruses and fungi (Abdel-Tawwab *et al.*, 2019; Akbary and Younesi, 2017). Various studies in broilers report improved growth and feed conversion (Huang *et al.*, 2005; Li *et al.*, 2007; Nuengjamnong and Angkanaporn, 2017; Shi *et al.*, 2005). Similarly, egg production in layers was improved by including chitin or its derivatives in hen diets (Meng *et al.*, 2010; Świątkiewicz *et al.*, 2013; Yan *et al.*, 2010). In pigs, various studies indicate improved weight gain, feed efficiency and a decrease in the commonly occurring weaning diarrhoea (Han *et al.*, 2007b; Liu *et al.*, 2008; Liu *et al.*, 2010). Other studies on pigs, however, found no effect of chitin and its derivatives (Han *et al.*, 2007a; Wang *et al.*, 2009). The growing consensus seems to be that a low inclusion level of chitin or its derivatives is beneficial both for production characteristics and for the health of the animal.

The move from traditional uses to more industrial uses of insects as food and feed, went along with other political, societal and academic developments. Very early on, the industry realized that legislation was one of the major hurdles to be crossed. For that reason, several insect producing companies in the European Union (EU) created in Brussels the 'International Platform of Insects for Food and Feed' (IPIFF) in 2013. Now IPIFF has 71 members representing the interests of the insect production sector to EU policy makers, European stakeholders and citizens. Through their efforts, the authorisation of insect proteins for use in aquafeed in the EU came into force in 2017, while the authorisation of insect-processed animal proteins (PAPs) in poultry and pig feed came into force in 2021 (IPIFF, 2024). IPIFF also issued several documents such as those dealing with good hygiene practices and insect frass as fertilizer. Also in the EU, the European Federation of Animal Science (EAAP) created in 2016 a study commission on insects (Veldkamp and Eilenberg, 2018). Since 2015 an annual event 'Insecta' has been organized in Germany (https://insecta-conference.com), and since 2014 there has also been the international conference 'Insects to Feed the World' with up to four live conferences in the Netherland, China, Canada, and Singapore, respectively. In North America the legislation on insects as feed is discussed by Larouche *et al.* (2023). In the USA the nongovernment Association of American Feed Control Officials (AAFCO) approved larval ingredients of dried and defatted black soldier fly as safe for adult dogs, poultry, swine and salmonid fish, while black soldier fly oil is approved for adult dogs, swine and finfish (as of today – May 2024).

In terms of academic interest, a search of Web of Science using the words 'insects' and 'animal feed' reveals that 71% of all publications were from the last five years (2019-2023) and 89% from the last 10 years from 1945 onwards, indicating that the interest is very recent. Also, several books and special issues with the theme 'Insects as Food and Feed' were published, while the journal, *Journal of Insects as Food and Feed*, has published over 650 articles since 2015. There are also several projects dealing with insects as food and feed, such as the EU projects 'SUStainable INsect CHAIN (SUSINCHAIN)' (2019-2023) (Veldkamp *et al.*, 2020), 'Valuable inSects' (VALUSECT) (2019-2023), and 'Enabling the exploitation of Insects as a Sustainable Source of Protein for Animal Feed and Human Nutrition' (PROteINSECT) (2013-2016). Ongoing PRIMA projects include: 'ADVAGROMED – Agroecological approaches based on the integration of insect farming with local field practices in Mediterranean countries' (2022-2025) and CIPROMED 'Circular and inclusive utilisation of alternative proteins in the Mediterranean value chains' (2023-2026) (https://prima-med.org/). The National Science Foundation (NSF), a United States federal agency, invested through the Industry-University Cooperative Research Centers (I/ UCRC) Program, to create the Center for Environmental Sustainability through Insect Farming (CEIF), a consortium integrating industry, government, and academia (Tomberlin *et al.*, 2022). The mission of the CEIF is to develop a global platform for the insects as food and industry to expand, diversify, and stabilise the insect agriculture sector.

Although insects are promising alternatives to conventional protein sources for ruminants, insect proteins are prohibited in these animals as they may be vectors of prions (Lalander and Vinnerås, 2022). However, safety data are required for verification (Renna *et al.*, 2023). Insect oils can be used and may potentially mitigate enteric methane emissions in ruminants (Ahmed *et al.*, 2021).

Insect meal is a promising alternative feed ingredient, but many factors need to be considered such as insect species, rearing substrates, production process, processing, insect meal form (whole or defatted), and inclusion levels (Gasco *et al.*, 2023b; Veldkamp *et al.*, 2023), as these may influence the digestibility and availability of nutrients and palatability. Another challenge of the industry is to have large and consistent quantities of insect ingredients that can be incorporated in the production process (Gasco *et al.*, 2023b,c).

The history of insects as animal feed is a testament to human ingenuity and adaptability in exploiting the potential of nature's resources. Insects are a valuable source of nutrition for animals, contributing to the sustainability and resilience of agricultural systems. As we confront the challenges of feeding a growing global population while minimizing environmental impact, insects are poised to play an increasingly prominent role in shaping the future of animal feed production.

Funding

No funding was provided to support this work.

References

Abanikannda, M.F., 2012. Nutrient digestibility and haematology of Nile tilapia (*Oreochromis niloticus*) fed with varying levels of locust (*Locusta migratoria*) meal. Dissertation, Bachelor of Aquaculture and Fisheries Management, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria, July 2012. Available at: https://api.semanticscholar.org/CorpusID:81674535

Abd El-Wahab, A., Meyer, L., Kölln, M., Chuppava, B., Wilke, V., Visscher, C. and Kamphues, J., 2021. Insect larvae meal (*Hermetia illucens*) as a sustainable protein source of canine food and its impacts on nutrient digestibility and fecal quality. Animals 11: 2525. https://doi.org/10.3390/ani11092525

Abdel-Tawwab, M., Razek, N.A. and Abdel-Rahman, A.M., 2019. Immunostimulatory effect of dietary chitosan nanoparticles on the performance of Nile tilapia, *Oreochromis niloticus* (L.). Fish & Shellfish Immunology 88: 254-258. https://doi.org/10.1016/j.fsi.2019.02.063

Adeyemo, G.O., Longe, O.G. and Lawal, H.A., 2008. Effects of feeding desert locust meal (*Schistocerca gregaria*) on performance and haematology of broilers. In: Proceedings of a conference on International Research and Food Security, Natural Resource Management and rural development. Tropentag 2008, October 7-9. University of Hohenheim, Germany. Available at: https://www.tropentag.de/2008/abstracts/full/623.pdf

Ahmed, E., Fukuma, N., Hanada, M. and Nishida, T., 2021. Insects as novel ruminant feed and a potential mitigation strategy for methane emissions. Animals 11: 2648. https://doi.org/10.3390/ani11092648

Akbary, P. and Younesi, A., 2017. Effect of dietary supplementation of Chitosan on growth, hematology and innate immunity of grey mullet (*Mugil cephalus*). Veterinary Research & Biological Products 30: 194-203. https://doi.org/10.22092/vj.2017.109873

Al-Salhie, K.C.K., Al-Hummod, S.K.M. and Jaber, F.N., 2021. The effect of using different levels of American cockroach (*Periplaneta americana*) powder on productive and physiological performance of Japanese quail (*Coturnix japonica*). IOP Conference Series: Earth and Environmental Science 735: 012003. https://doi.org/10.1088/1755-1315/735/1/012003

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

Amao, O.A., Oladunjoye, I.O., Togun, V.A., Olubajo, K. and Oyaniyi, O., 2010. Effect of Westwood (*Cirina forda*) larva meal on the laying performance and egg characteristics of laying hen in a tropical environment. International Journal of Poultry Science 9: 450-454. https://doi.org/10.3923/ijps.2010.450.454

Amer, A.A., El-Nabawy, E.-S.M., Gouda, A.H. and Dawood, M.A.O., 2021. The addition of insect meal from *Spodoptera littoralis* in the diets of Nile tilapia and its effect on growth rates, digestive enzyme activity and health status. Aquaculture Research 52: 5585-5594. https://doi.org/10.1111/are.15434

Anand, H., Ganguly, A. and Haldar, P., 2008. Potential value of acridids as high protein supplement for poultry feed. International Journal of Poultry Science 7: 722-725. https://doi.org/10.3923/ijps.2008.722.725

Aniebo, A.O., Erondu, E.S. and Owen, O.J., 2008. Proximate composition of housefly larvae (*Musca domestica*) meal generated from mixture of cattle blood and wheat bran. Livestock Research for Rural Development 20: 205. Available at: http://www.lrrd.org/lrrd20/12/anie20205.htm

Anonymous, 2019. Growing insects as alternative protein source for fish food. Leaffin, May 20. Available at: https://www.leaffin.com/feed-fish-protein-rich-insects

Anvo, M.P.M., Aboua, B.R.D., Compaoré, I., Sissao, R., Zoungrana-Kaboré, C.Y., Kouamelan, E.P. and Toguyéni, A., 2017. Fish meal replacement by *Cirina butyrospermi* caterpillar's meal in practical diets for *Clarias gariepinus* fingerlings. Aquaculture Research 48: 5243-5250. https://doi.org/10.1111/are.13337

Areerat, S., Chundang, P., Lekcharoensuk, C. and Kovitvadhi, A., 2021. Possibility of using house cricket (*Acheta domesticus*) or mulberry silkworm (*Bombyx mori*) pupae meal to replace poultry meal in canine diets based on health and nutrient digestibility. Animals 11: 2680. https://doi.org/10.3390/ani11092680

Areerat, S., Chundang, P., Lekcharoensuk, C., Patumcharoenpol, P. and Kovitvadhi, A., 2023. Insect-based diets (house crickets and mulberry silkworm pupae): a comparison of their effects on canine gut microbiota. Veterinary World 16: 1627-1635. https://doi.org/10.14202/vetworld.2023.1627-1635

Bernstein, D.I., Gallagher, J.S. and Leonard Bernstein, I., 1983. Mealworm asthma: clinical and immunologic studies. Journal of Allergy and Clinical Immunology 72: 475-480. https://doi.org/10.1016/0091-6749(83)90584-5

Biasato, I., Gasco, L., Schiavone, A., Capucchio, M.T. and Ferrocino, I., 2023. Gut microbiota changes in insect-fed monogastric species: state-of-the-art and future perspectives. Animal Frontiers 13: 72-80. https://doi.org/10.1093/af/vfad025

Boafo, H.A., Affedzie-Obresi, S., Gbemavo, D.S.J.C., Clottey, V.A., Nkegbe, E., Adu-Aboagye, G. and Kenis, M., 2019. Use of termites by farmers as poultry feed in Ghana. Insects 10: 69. https://doi.org/10.3390/insects10030069

Boko, K.C., Kpodekon, T.M., Dahouda, M., Marlier, D. and Mainil, J.G., 2012. Contraintes techniques et sanitaires de la production traditionnelle de pintade en Afrique subsaharienne. Annales De Médecine Vétérinaire 156: 25-36.

Booth, D.C. and Sheppard, C., 1984. Oviposition of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae): eggs, masses, timing, and site characteristics. Environmental Entomology 13: 421-423. https://doi.org/10.1093/ee/13.2.421

Bosch, G. and Swanson, K.S., 2021. Effect of using insects as feed on animals: pet dogs and cats. Journal of Insects as Food and Feed 7: 795-805. https://doi.org/10.3920/JIFF2020.0084

Bosch, G., Zhang, S., Oonincx, D.G.A.B. and Hendriks, W.H., 2014. Protein quality of insects as potential ingredients for dog and cat foods. Journal of Nutritional Science 3: e29. https://doi.org/10.1017/jns.2014.23

Bouafou, K.G.M., Kouame, K.G., Amoikon, K.E. and Offoumou, A.M., 2006. Potentiel pour la production d'asticots sur des sous-produits en Côte d'Ivoire. Tropicultura 24: 157-161.

Breeden, G.C., Turner, E.C., Jr. and Beane, W.L., 1975. Methoprene as a feed additive for control of the house fly breeding in chicken manure. Journal of Economic Entomology 68: 451-452. https://doi.org/10.1093/jee/68.4.451

Buisseret, P., 1978. Seasonal asthma in an angler. The Lancet 311: 668. https://doi.org/10.1016/S0140-6736(78)91180-7

Calvert, C.C., Martin, R.D. and Morgan, N.O., 1969. House fly pupae as food for poultry. Journal of Economic Entomology 62: 938-939. https://doi.org/10.1093/jee/62.4.938

Calvert, C.C., Morgan, N.O. and Martin, R.D., 1970. House fly larvae: biodegradation of hen excreta to useful products. Poultry Science 49: 588-589. https://doi.org/10.3382/ps.0490588

Capinera, L., 2010. Insects and wildlife. Wiley-Blackwell, Chichester, UK. https://doi.org/10.1002/9781444317688

Cervo, I.B. and Guadagnin, D.L., 2020. Wild boar diet and its implications on agriculture and biodiversity in Brazilian forest – grassland ecoregions. Animal Biodiversity and Conservation 34: 123-136. https://doi.org/10.32800/abc.2020.43.0123

Chrappa, V., Peter, V., Strózyk, Z. and Slamedka, J., 1990. The effects of the feeding of poultry dung cultured by housefly (*Musca domestica* l.) larvae on the efficiency of broiler chicks. Scientia Agriculturae Bohemoslovaca 22: 131-138.

Clark, M.S. and Gage, S.H., 1996. Effects of free-range chickens and geese on insect pests and weeds in an agroecosystem. American Journal of Alternative Agriculture 11: 39-47. https://doi.org/10.1017/S0889189300006718

Copes, F. and Meronek, T., 1995. An overview of the regional bait industry. In: Proceedings Combined North Central and Ninth Annual Minnesota Aquaculture Conference and Tradeshow – Research & Industry: Working Together to Advance Aquaculture in the North Central Region, February 17-18, 1995, Minneapolis, MN, USA.

Cowan, F.T., 1929. Life history, habits and control of the Mormon cricket. United States Department of Agriculture, Washington, DC, USA, Techn. Bulletin No.161.

Dankwa, D., Nelson, F.S., Oddoye, E.O.K. and Duncan, J.L., 2002. Housefly larvae as a feed supplement for rural poultry. Ghana Journal of Agricultural Science 35: 185-187.

Dao, A.N., Sankara, F., Pousga, S., Coulibaly, K., Nacoulma, J.P., Somda, I. and Kenis, M., 2022. Sustainable use of *Macrotermes* spp. to improve traditional poultry farming through an efficient trapping system in Burkina Faso. Insects 13: 62. https://doi.org/10.3390/insects13010062

Dao, A.N.C., Nacambo, S., Sankara, F., Pousga, S., Coulibaly, K., Nacoulma, J.P., Somda, I. and Kenis, M., 2020. Evaluation of termite trapping methods in northern Burkina Faso. International Journal of Biological and Chemical Sciences 14: 2556-2566. https://dx.doi.org/10.4314/ijbcs.v14i7.15

De Jong, B. and Nikolik, G., 2021. No longer crawling: Insect protein to come of age in the 2020s: scaling up is on the horizon. RaboResearch: Food & Agribusiness, Utrecht, the Netherlands. Available at: https://research.rabobank.com/far/en/sectors/animal-protein/insect-protein-to-come-of-age-in-the-2020s.html

Deblauwe, I. and Janssens, G.P.J., 2008. New insights in insect prey choice by chimpanzees and gorillas in Southeast Cameroon: the role of nutritional value. American Journal of Physical Anthropology 135: 42-55. https://doi.org/10.1002/ajpa.20703

DeFoliart, G.R., 1995. Edible insects as minilivestock. Biodiversity and Conservation 4: 306-321. https://doi.org/10.1007/BF00055976

Defoliart, G.R., Finke, M.D. and Sunde, M.L., 1982. Potential value of the Mormon cricket (Orthoptera: Tettigoniidae) harvested as a high-protein feed for poultry. Journal of Economic Entomology 75: 848-852. https://doi.org/10.1093/jee/75.5.848

Deng, B., Luo, J., Xu, C., Zhang, X., Li, J., Yuan, Q. and Cao, H., 2024. Biotransformation of Pb and As from sewage sludge and food waste by black soldier fly larvae: migration mechanism of bacterial community and metalloregulatory protein scales. Water Research 254: 121405. https://doi.org/10.1016/j.watres.2024.121405

Deruytter, D., Gasco, L., Yakti, W., Katz, H., Coudron, C.L., Gligorescu, A., Frooninckx, L., Noyens, I., Meneguz, M., Grosso, F., Bellezza Oddon, S., Biasato, I., Mielenz, M., Veldkamp, T., Van Loon, J.J.A., Spranghers, T., Vandenberg, G.W., Oonincx, D.G.A.B. and Bosch, G., 2023. Standardising black soldier fly larvae feeding experiments: an initial protocol and variability estimates. Journal of Insects as Food and Feed. https://doi.org/10.1163/23524588-20230008

Despins, J.L. and Axtell, R.C., 1995. Feeding behavior and growth of broiler chicks fed larvae of the Darkling beetle, *Alphitobius diaperinus*. Poultry Science 74: 331-336. https://doi.org/10.3382/ps.0740331

Dhaliwal, J.S., Virk, R.S. and Atwal, A.S., 1981. The use of house fly (*Musca domestica* Linnaeus) pupae meal in broiler mash. Indian Journal of Poultry Science 15: 119-122.

DiGiacomo, K. and Leury, B.J., 2019. Review: Insect meal: a future source of protein feed for pigs? Animal 13: 3022-3030. https://doi.org/10.1017/S1751731119001873

Ditchkoff, S.S. and Mayer, J.J., 2009. Biology of wild pigs: Wild pig food habits. In: Mayer, J.J. and Brisbin, I.L. (eds.) Wild pigs: biology, damage, control techniques and management. Savannah River National Laboratory, Aiken, SC, USA, pp. 105-144.

Dörper, A., Veldkamp, T. and Dicke, M., 2021. Use of black soldier fly and house fly in feed to promote sustainable poultry production. Journal of Insects as Food and Feed 7: 761-780. https://doi.org/10.3920/JIFF2020.0064

Dufour, D.L., 1987. Insects as food: a case study from the northwest Amazon. American Anthropologist 89: 383. https://doi.org/10.1525/aa.1987.89.2.02a00070

Ekonda, M., 2012. Synthèse des travaux de recherches sur la production d'asticot pour l'alimentation des monogastriques: Cas de la volaille et de rongeur. Département de Zootechnie, Faculté de Médecine Vétérinaire, Université de Kinshasa, Kinshasa, Democratic Republic of the Congo.

El Boushy, A.R., 1991. House-fly pupae as poultry manure converters for animal feed: a review. Bioresource Technology 38: 45-49. https://doi.org/10.1016/0960-8524(91)90220-E

Emehinaiye, P.A., 2012. Growth performance of *Oreochromis niloticus* fingerlings fed with varying levels of migratory locust (*Locusta migratoria*) meal. Bachelor of Aquaculture and Fisheries Management, Federal University of Agriculture, Abeokuta, Nigeria.

Esteban, M.A., Cuesta, A., Ortuño, J. and Meseguer, J., 2001. Immunomodulatory effects of dietary intake of chitin on gilthead seabream (*Sparus aurata* L.) innate immune system. Fish & Shellfish Immunology 11: 303-315. https://doi.org/10.1006/fsim.2000.0315

Fagoonee, I., 1983. Inclusion of silkworm pupae in poultry rations. Tropical Veterinary Journal 1: 91-96.

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

Feng, Y., Chen, X.-M., Zhao, M., He, Z., Sun, L., Wang, C.-Y. and Ding, W.-F., 2018. Edible insects in China: utilization and prospects. Insect Science 25: 184-198. https://doi.org/10.1111/1744-7917.12449

Figueirêdo, R.E.C.R., Vasconcellos, A., Policarpo, I.S. and Alves, R.R.N., 2015. Edible and medicinal termites: a global overview. Journal of Ethnobiology and Ethnomedicine 11: 29. https://doi.org/10.1186/s13002-015-0016-4

Gasco, L., Biasato, I., Enes, P. and Gai, F., 2023a. Chapter 16 – Potential and challenges for the use of insects as feed for aquaculture. In: Morales-Ramos, J.A., Rojas, M.G. and Shapiro-Ilan, D.I. (eds.) Mass production of beneficial organisms. 2nd ed. Academic Press, Cambridge, MA, USA, pp. 465-492. https://doi.org/10.1016/B978-0-12-822106-8.00009-9

Gasco, L., Józefiak, A. and Henry, M., 2021. Beyond the protein concept: health aspects of using edible insects on animals. Journal of Insects as Food and Feed 7: 715-741. https://doi.org/10.3920/JIFF2020.0077

Gasco, L., Oddon, S.B., Vandenberg, G.W., Veldkamp, T. and Biasato, I., 2023b. Factors affecting the decision-making process of using insect-based products in animal feed formulations. Journal of Insects as Food and Feed. https://doi.org/10.3920/JIFF2022.0164

Gasco, L., Renna, M., Bellezza Oddon, S., Rezaei Far, A., Naser El Deen, S. and Veldkamp, T., 2023c. Insect meals in a circular economy and applications in monogastric diets. Animal Frontiers 13: 81-90. https://doi.org/10.1093/af/vfad016

Goromela, E.H., Kwakkel, R.P., Verstegen, M.W.A. and Katule, A.M., 2006. Strategies to optimize the use of scavengeable feed resource base by smallholders in traditional poultry production systems in Africa: a review. African Journal of Agricultural Research 1: 91-100.

Graves, K.G. and Morrow, J.C., 1988. Method for harvesting large quantities of zooplankton from hatchery ponds. The Progressive Fish-Culturist 50: 184-186. https://doi.org/10.1577/1548-8640(1971)33[187:UOULTI]2.0.CO;2

Hale, O.M., 1973. Dried *Hermetia illucens* larvae (Diptera: Stratiomyidae) as a feed additive for poultry. Journal of the Georgia Entomological Society 8: 16-20.

Han, K., Yang, Y., Hahn, T., Kwon, I., Lohakare, J., Lee, J. and Chae, B., 2007a. Effects of chito-oligosaccharides supplementation on performance, nutrient digestibility, pork quality and immune response in growing-finishing pigs. Journal of Animal and Feed Sciences 16: 607-620. https://doi.org/10.22358/jafs/66818/2007

Han, K.N., Kwon, I.K., Lohakare, J., Heo, S. and Chae, B.J., 2007b. Chito-oligosaccharides as an alternative to antimicrobials in improving performance, digestibility and microbial ecology of the gut in weanling pigs. Asian-Australasian Journal of Animal Sciences 20: 556-562. https://doi.org/10.5713/ajas.2007.556

Harder, T.M. and Gotsch, G.G., 2007. Nighttime lighting and feeding in ponds enhance survival of fingerling walleyes during habituation to manufactured feed. North American Journal of Aquaculture 69: 250-256. https://doi.org/10.1577/A06-015.1

Harikrishnan, R., Kim, J.-S., Balasundaram, C. and Heo, M.-S., 2012. Dietary supplementation with chitin and chitosan on haematology and innate immune response in *Epinephelus bruneus* against *Philasterides dicentrarchi*. Experimental Parasitology 131: 116-124. https://doi.org/10.1016/j.exppara.2012.03.020

He, W., Li, P. and Wu, G., 2021. Amino acid nutrition and metabolism in chickens. In: Wu, G. (ed.) Amino acids in nutrition and health: amino acids in the nutrition of companion, zoo and farm animals. Springer, Cham, Switzerland, pp. 109-131. https://doi.org/10.1007/978-3-030-54462-1_7

Heidinger, R.C., 1971. Use of ultraviolet light to increase the availability of aerial insects to caged bluegill sunfish. The Progressive Fish-Culturist 33: 187-192. https://doi.org/10.1577/1548-8640(1971)33[187:UOULTI]2.0.CO;2

Hem, S., Toure, S., Sagbla, C. and Legendre, M., 2008. Bioconversion of palm kernel meal for aquaculture: experiences from the forest region (Republic of Guinea). African Journal of Biotechnology 7: 1192-1198.

Henry, M., Gasco, L., Piccolo, G. and Fountoulaki, E., 2015. Review on the use of insects in the diet of farmed fish: past and future. Animal Feed Science and Technology 203: 1-22. https://doi.org/10.1016/j.anifeedsci.2015.03.001

Hernández-Martínez, M., Ramos-Elorduy, J., Pino-Moreno, J.M. and Acosta-Castañeda, C., 2008. Evaluación de dietas con inclusión de *Periplaneta americana* L. en el crecimiento de la carpa japonesa. Ciencia Pesquera 16: 23-28.

Heuser, G.F., 1941. Protein in poultry nutrition – a review. Poultry Science 20: 362-368. https://doi.org/10.3382/ps.0200362

Hien, O.C., Bougouma, V. and Some, W., 2010. Effets de la substitution de la farine de poisson par celle de chenilles de karite (*Cirina butyrospermi* Vuillet) sur la croissance et les parametres de ponte chez des poules de souche « Isa-Brown ». Science et technique: Sciences naturelles et agronomic 32: 21-32.

Hien, O.C., Diarra, B., Drabo, Y., Boly, H. and Sawadogo, L., 2005. Pratiques de l'aviculture traditionnelle par les differents groupes ethniques de la region des Cascades au Burkina Faso. Agronomie Africaine 17: 227-239.

Hollingsworth, R.W., 1967. Iowa's great lakes … winter fishing bonanza. Iowa Conservationist 26: 89, 92.

Hong, J. and Kim, Y.Y., 2022. Insect as feed ingredients for pigs. Animal Bioscience 35: 347-355. https://doi.org/10.5713/ab.21.0475

Huang, R., Yin, Y., Wu, G., Zhang, Y., Li, T., Li, L., Li, M., Tang, Z., Zhang, J., Wang, B., He, J. and Nie, X., 2005. Effect of dietary oligochitosan supplementation on ileal digestibility of nutrients and performance in broilers. Poultry Science 84: 1383-1388. https://doi.org/10.1093/ps/84.9.1383

Huque, Q.M.E., 1999. Nutritional status of family poultry in Bangladesh. Livestock Research for Rural Development 11: 28. http://www.lrrd.org/lrrd11/3/huq113.htm

Ijaiya, A. and Eko, E.O., 2009. Effect of replacing dietary fish meal with silkworm (*Anaphe infracta*) caterpillar meal on growth, digestibility and economics of production of starter broiler chickens. Pakistan Journal of Nutrition 8: 845-849. https://doi.org/10.3923/pjn.2009.845.849

IPIFF, 2024. International Platform of Insects for Food and Feed (IPIFF), Brussels, Belgium. Available at: https://ipiff.org/

Iroko, A.F., 1996. L'homme et les termitières en Afrique. Editions Karthala, Paris, France.

Jelbert, S., 2021. Bait fishing. In: Shackelford, T.K. and Weekes-Shackelford, V.A. (eds.) Encyclopedia of evolutionary psychological science. Springer, Cham, Switzerland, pp. 501-504. https://doi.org/10.1007/978-3-319-19650-3_3165

Johansen, M., Erkinaro, J. and Amundsen, P., 2011. The when, what and where of freshwater feeding. In: Aas, Ø., Klemetsen, A., Einum, S. and Skurdal, J. (eds.) Atlantic salmon ecology. Blackwell Publishing Ltd., Hoboken, NJ, USA, pp. 89-114.

Joshi, P., Rao, P., Mitra, A. and Rao, B., 1980. Evaluation of deoiled silkworm pupae-meal on layer performance. Indian Journal of Animal Science 50: 979-982.

Joubert, R., 2012. Turning a pest into protein. Farmer's Weekly, 18 October 2012. Available at: https://www.farmersweekly.co.za/agri-news/south-africa/turning-a-pest-into-protein

Kenis, M., Koné, N., Chrysostome, C.A.A.M., Devic, E., Koko, G.K.D., Clottey, V.A., Nacambo, S. and Mensah, G.A., 2014. Insects used for animal feed in West Africa. Entomologia 2: 107-114.

Kępińska-Pacelik, J. and Biel, W., 2022. Insects in pet food industry – Hope or threat? Animals 12: 1515. https://doi.org/10.3390/ani12121515

Khaekratoke, K., Laksanawimol, P. and Thancharoen, A., 2022. Use of fermented spent coffee grounds as a substrate supplement for rearing black soldier fly larvae, *Hermetia illucens* (L), (Diptera: Stratiomyidae). PeerJ 10: e14340. https://doi.org/10.7717/peerj.14340

Khusro, M., Andrew, N.R. and Nicholas, A., 2012. Insects as poultry feed: a scoping study for poultry production systems in Australia. World's Poultry Science Journal 68: 435-446. https://doi.org/10.1017/S0043933912000554

Koné, N., Sylla, M., Nacambo, S. and Kenis, M., 2017. Production of house fly larvae for animal feed through natural oviposition. Journal of Insects as Food and Feed 3: 177-186. https://doi.org/10.3920/jiff2016.0044

Kongsup, P., Lertjirakul, S., Chotimanothum, B., Chundang, P. and Kovitvadhi, A., 2023. Effects of eri silkworm (*Samia ricini*) pupae inclusion in broiler diets on growth performances, health, carcass characteristics and meat quality. Animal Bioscience 35: 711-720. https://doi.org/10.5713/ab.21.0323

Krishnan, R., Sherin, L., Muthuswami, M., Balagopal, R. and Jayanthi, C., 2011. Seri waste as feed substitute for broiler production. Sericologia 51: 369-377.

Lalander, C. and Vinnerås, B., 2022. Actions needed before insects can contribute to a real closed-loop circular economy in the EU. Journal of Insects as Food and Feed 8: 337-342. https://doi.org/10.3920/JIFF2022.x003

La Rivers, I., 1941. The Mormon cricket as food for birds. The Condor 43: 65-69. https://doi.org/10.2307/1364022

Larouche, J., Campbell, B., Hénault-Éthier, L., Banks, I.J., Tomberlin, J.K., Preyer, C., Deschamps, M.-H. and Vandenberg, G.W., 2023. The edible insect sector in Canada and the United States. Animal Frontiers 13: 16-25. https://doi.org/10.1093/af/vfad047

Lestingi, A., 2024. Alternative and sustainable protein sources in pig diet: a review. Animals 14: 310. https://doi.org/10.3390/ani14020310

Li, X.J., Piao, X.S., Kim, S.W., Liu, P., Wang, L., Shen, Y.B., Jung, S.C. and Lee, H.S., 2007. Effects of chito-oligosaccharide supplementation on performance, nutrient digestibility, and serum composition in broiler chickens. Poultry Science 86: 1107-1114. https://doi.org/10.1093/ps/86.6.1107

Liland, N.S., Araujo, P., Xu, X.X., Lock, E.J., Radhakrishnan, G., Prabhu, A.J.P. and Belghit, I., 2021. A meta-analysis on the nutritional value of insects in aquafeeds. Journal of Insects as Food and Feed 7: 743-759. https://doi.org/10.3920/JIFF2020.0147

Lisenko, K.G., Godoy, M.R.C., Oliveira, K.R.B., Oliveira, M.R.D., Silva, T.V., Fontes, T.V., Lacerda, R.F., Ferreira, L.G., Gonçalves, T.M., Zangeronimo, M.G., da Costa, D.V. and Saad, F.M.O.B., 2023. Digestibility of insect meals for dogs and their effects on blood parameters, faecal characteristics, volatile fatty acids, and gut microbiota. Journal of Insects as Food and Feed 9: 907-918. https://doi.org/10.3920/JIFF2022.0114

Liu, P., Piao, X.S., Kim, S.W., Wang, L., Shen, Y.B., Lee, H.S. and Li, S.Y., 2008. Effects of chito-oligosaccharide supplementation on the growth performance, nutrient digestibility, intestinal morphology, and fecal shedding of *Escherichia coli* and *Lactobacillus* in weaning pigs. Journal of Animal Science 86: 2609-2618. https://doi.org/10.2527/jas.2007-0668

Liu, P., Piao, X.S., Thacker, P.A., Zeng, Z.K., Li, P.F., Wang, D. and Kim, S.W., 2010. Chito-oligosaccharide reduces diarrhea incidence and attenuates the immune response of weaned pigs challenged with *Escherichia coli* K881. Journal of Animal Science 88: 3871-3879. https://doi.org/10.2527/jas.2009-2771

Loboguerrero, A.M., Thornton, P., Wadsworth, J., Campbell, B.M., Herrero, M., Mason-D'Croz, D., Dinesh, D., Huyer, S., Jarvis, A., Millan, A., Wollenberg, E. and Zebiak, S., 2020. Perspective article: actions to reconfigure food systems. Global Food Security 26: 100432. https://doi.org/10.1016/j.gfs.2020.100432

Macadam, C.R. and Stockan, J.A., 2015. More than just fish food: ecosystem services provided by freshwater insects. Ecological Entomology 40: 113-123. https://doi.org/10.1111/een.12245

Makkar, H.P.S., Tran, G., Heuzé, V. and Ankers, P., 2014. State-of-the-art on use of insects as animal feed. Animal Feed Science and Technology 197: 1-33. https://doi.org/10.1016/j.anifeedsci.2014.07.008

McCafferty, W.P. and Provonsha, A.V., 1998. Aquatic entomology: the fishermen's and ecologists' illustrated guide to insects and their relatives. Jones and Bartlett Publishers, Boston, MA, USA.

Men, B.X., Tinh, T.K., Preston, T.R., Ogle, R.B. and Lindberg, J.E., 1999. Use of local ducklings to control insect pests and weeds in the growing rice field. Livestock Research for Rural Development 11: 15.

Meng, Q.W., Yan, L., Ao, X., Jang, H.D., Cho, J.-H. and Kim, I.-S., 2010. Effects of chito-oligosaccharide supplementation on egg production, nutrient digestibility, egg quality and blood profiles in laying hens. Asian-Australasian Journal of Animal Sciences 23: 1476-1481. https://doi.org/10.5713/ajas.2010.10025

Merkowsky, A.J., Handcock, A.J. and Newton, S.H., 1977. Attraction of aerial insects as a fish food supplement. Journal of the Arkansas Academy of Science 31: 24. Available at: https://scholarworks.uark.edu/jaas/vol31/iss1/24

Meronek, T.G., Copes, F.A. and Coble, D.W., 1997. A survey of the bait industry in the north-central region of the United States. North American Journal of Fisheries Management 17: 703-711. https://doi.org/10.1577/1548-8675(1997)017<0703:ASOTBI>2.3.CO;2

Miller, B.F., Teotia, J.S. and Thatcher, T.O., 1974. Digestion of poultry manure by *Musca domestica*. British Poultry Science 15: 231-234. https://doi.org/10.1080/00071667408416100

Miranda, D.C., Cammack, A.J. and Tomberlin, K.J., 2019. Interspecific competition between the house fly, *Musca domestica* L. (Diptera: Muscidae) and black soldier fly, *Hermetia illucens* (L.) (Diptera: Stratiomyidae) when reared on poultry manure. Insects 10: 440. https://doi.org/10.3390/insects10120440

Mischke, C.C., Li, M.H. and Oberle, D.F., 2011. Can reduced stocking rates and bug lights produce market-sized catfish from fingerlings in one growing season? Journal of Applied Aquaculture 23: 271-278. https://doi.org/10.1080/10454438.2011.601256

Moreki, J., Tiroesele, B. and Chiripasi, S.C., 2012. Prospects of utilizing insects as alternative sources of protein in poultry diets in Botswana. Journal of Animal Science Advances 2: 649-658.

Morse, J.C., 2017. Biodiversity of aquatic insects. In: Foottit, R.G. and Adler, P.H. (eds.) Insect biodiversity: science and society. Blackwell Publishing, Oxford, UK, pp. 205-227. https://doi.org/10.1002/9781118945568.ch8

Mottet, A. and Tempio, G., 2017. Global poultry production: current state and future outlook and challenges. World's Poultry Science Journal 73: 245-256. https://doi.org/10.1017/S0043933917000071

Mpoame, M., Téguia, A. and Nguemfo, E.L., 2004. Essai comparé de production d'asticots dans les fientes de poule et dans la bouse de vache. Tropicultura 22: 84-87.

Munyuli Bin Mushambanyi, T.a.N.B., 2002. Utilisation des blattes et des termites comme substituts potentiels de la farine de viande dans l'alimentation des poulets de chair au Sud-Kivu, République Démocratique du Congo. Tropicultura 20: 10-16.

Musundire, R., Ngonyama, D., Ngadze, R.T., Musundire, R., Malete, J.J., Matanda, M.J., Tarakini, T., Langton, M. and Chiwona-Karltun, L., 2021. Stewardship of wild and farmed edible insects as food and feed in Sub-Saharan Africa: a perspective. Frontiers in Veterinary Science 8: 601386. https://doi.org/10.3389/fvets.2021.601386

Nairuti, R.N., Musyoka, S.N., Yegon, M.J. and Opiyo, M.A., 2022. Utilization of black soldier fly (*Hermetia illucens* Linnaeus) larvae as a protein source for fish feed: a review.

Aquaculture Studies 22: AQUAST697. http://doi.org/10.4194/AQUAST697

Nakagaki, B.J., Sunde, M.L. and Defoliart, G.R., 1987. Protein quality of the house cricket, *Acheta domesticus*, when fed to broiler chicks. Poultry Science 66: 1367-1371. https://doi.org/10.3382/ps.0661367

Newton, G.L., Booram, C.V., Barker, R.W. and Hale, O.M., 1977b. Dried *Hermetia illucens* larvae meal as supplement for swine. Journal of Animal Science 44: 395-400. https://doi.org/10.2527/jas1977.443395x

Nnaji, C.J. and Okoye, F.C., 2005. Substituting fish meal with grasshopper meal in the diet of *Clarias gariepinus* fingerlings. In: 19th Annual Conference of the Fisheries Society of Nigeria (FISON), 29 November – 3 December 2004. Ilorin, Nigeria, pp. 37-44. Available at: http://hdl.handle.net/1834/21644

Nuengjamnong, C. and Angkanaporn, K., 2018. Efficacy of dietary chitosan on growth performance, haematological parameters and gut function in broilers. Italian Journal of Animal Science 17: 428-435. https://doi.org/10.1080/1828051X.2017.1373609

Nyakeri, E.M., Ogola, H.J., Ayieko, M.A. and Amimo, F.A., 2017. An open system for farming black soldier fly larvae as a source of proteins for smallscale poultry and fish production. Journal of Insects as Food and Feed 3: 51-56. https://doi.org/10.3920/jiff2016.0030

Nyangena, D., Mutungi, C., Imathiu, S., Kinyuru, J., Affognon, H., Ekesi, S., Nakimbugwe, D. and Fiaboe, K., 2020. Effects of traditional processing techniques on the nutritional and microbiological quality of four edible insect species used for food and feed in East Africa. Foods 9: 574. https://doi.org/10.3390/foods9050574

Nyffeler, M., Şekercioğlu, Ç.H. and Whelan, C.J., 2018. Insectivorous birds consume an estimated 400-500 million tons of prey annually. The Science of Nature 105: 47. https://doi.org/10.1007/s00114-018-1571-z

Nzamujo, O.P., 1999. Technique for maggot production – the Songhai experience. Songhai Centre, Porto Nove, Benin. Available at: https://www.hourofthetime.com/lib/Animal%20Husbandry/maggotry.pdf

Ocio, E., Viñaras, R. and Rey, J.M., 1979. Housefly larvae meal grown on municipal organic waste as a source of protein in poultry diets. Animal Feed Science and Technology 4: 227-231. https://doi.org/10.1016/0377-8401(79)90016-6

Ojewola, G.S., Eburuaja, A.S., Okoye, F.C., Lawal, A.S. and Akinmutimi, A.H., 2003. Effect of inclusion of grasshopper meal on performance, nutrient utilization and organ of broiler chicken. Journal of Sustainable Agriculture and the Environment 5: 19-25. https://doi.org/10.3923/ijps.2005.462.467

Ojewola, G.S., Okoye, F.C. and Ukoha, O.A., 2005. Comparative utilization of three animal protein sources by broiler chickens. International Journal of Poultry Science 4: 462-467.

Okoye, F.C. and Nnaji, J.C., 2005. Effects of substituting fish meal with grasshopper meal on growth and food utilization of the Nile tilapia, *Oreochromis niloticus* fingerlings. In: 19th Annual Conference of the Fisheries Society of Nigeria (FISON), 29 November – 3 December 2004. Ilorin, Nigeria, pp. 37-44. Available at: http://hdl.handle.net/1834/21778

Omole, A.J., Ogbosuka, G.E., Salako, R.A. and Ajayi, O.O., 2005. Effect of replacing oyster shell with gypsum in broiler finisher diet. Journal of Applied Sciences Research 1: 245-248.

Oonincx, D.G.A.B. and Finke, M.D., 2023. Insects as a complete nutritional source. Journal of Insects as Food and Feed 9: 541-543. https://doi.org/10.3920/JIFF2023.x002

Oyegoke, O.O., Akintola, A.J. and Fasoranti, J.O., 2006. Dietary potentials of the edible larvae of *Cirina forda* (Westwood) as a poultry feed. African Journal of Biotechnology 5: 1799-1802.

Ozimek, L., Sauer, W.C., Kozikowski, V., Ryan, J.K., Jorgensen, H. and Jelen, P., 1985. Nutritive value of protein extracted from honey bees. Journal of Food Science 50: 1327-1329.

Papp, L., 1975. House fly larvae as protein source from pig manure. Folia Entomologica Hungarica 28: 127-136.

Pearre and Maass, 1998. Trends in the prey size-based trophic niches of feral and house cats *Felis catus* L. Mammal Review 28: 125-139. https://doi.org/10.1046/j.1365-2907.1998.00030.x

Peterson, A., 1956. Fishing with natural insects. A handbook of insects for bait use. Ohio Spahr & Glenn Company, Columbus, OH, USA, 176 pp.

Plantinga, E., Bosch, G. and Hendriks, W., 2011. Estimation of the dietary nutrient profile of free-roaming feral cats: possible implications for nutrition of domestic cats. British Journal of Nutrition 106: 35-48. https://doi.org/10.1017/S0007114511002285

Pomalégni, S.C.B., Gbemavo, D.S.J.C., Kpadé, C.P., Kenis, M. and Mensah, G.A., 2017. Traditional use of fly larvae by small poultry farmers in Benin. Journal of Insects as Food and Feed 3: 187-192. https://doi.org/10.3920/JIFF2016.0061

Porcel Carreño, S., Pineda de la Losa, F., Frontera Carrion, E., Rodríguez Martín, E., Ramos Cantariño, A., Sánchez González, A., Rodríguez Trabado, A., Jiménez Timón, S., Alvarado Arenas, M., Víctor Medina Velasco, V., Rodríguez Martín, M. and Hernández Arbeiza, J., 2009. *Protophormia terraenovae*. A new allergenic species in amateur fishermen of Caceres, Spain. Allergologia et Immunopathologia 37: 68-72. https://doi.org/10.1016/S0301-0546(09)71107-3

Radclife, W., 1921. Fishing from the earliest times. J. Murray Publisher, London, UK. https://doi.org/10.5962/bhl.title.11792

Ramos-Elorduy, J., González, E.A., Hernández, A.R. and Pino, J.M., 2002. Use of *Tenebrio molitor* (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens. Journal of Economic Entomology 95: 214-220. https://doi.org/10.1603/0022-0493-95.1.214

Rapatsa, M.M. and Moyo, N.A.G., 2017. The potential role of night-time lighting in attracting terrestrial insects as food for *Oreochromis mossambicus* and *Clarias gariepinus*. Tropical Zoology 30: 156-169. https://doi.org/10.1080/03946975.2017.1362841

Rashid, M., Roy, B.C. and Asaduzzaman, 2004. Chemical composition of crop contents of local scavenging chickens. Pakistan Journal of Nutrition 3: 26-28.

Ravindran, V. and Blair, R., 1993. Feed resources for poultry production in Asia and the Pacific. Animal protein sources. World's Poultry Science Journal 49: 219-235. https://doi.org/10.1079/WPS19930020

Réglade, M.A., Dilawar, E.M. and Anand, U., 2015. Active bait-fishing in Indian pond heron *Ardeola grayii*. Indian Birds 10: 124-125.

Renna, M., Rastello, L., Veldkamp, T., Toral, P.G., Gonzalez-Ronquillo, M., Jimenez, L.E.R. and Gasco, L., 2023. Are insects a solution for feeding ruminants? Legislation, scientific evidence, and future challenges. Animal Frontiers 13: 102-111. https://doi.org/10.1093/af/vfad026

Riddick, E.W., 2014. Chapter 16 – Insect protein as a partial replacement for fishmeal in the diets of juvenile fish and crustaceans. In: Morales-Ramos, J.A., Guadalupe Rojas, M. and Shapiro-Ilan, D. (eds.) Mass production of beneficial organisms. Academic Press, Cambridge, MA, USA, pp. 565-582. http://dx.doi.org/10.1016/B978-0-12-391453-8.00016-9

Riise, J.C., Permin, A., Vesterlund McAinsh, C. and Frederiksen, L., 2004. Keeping village poultry: a technical manual on small-scale poultry production. Network for Smallholder Poultry Development.

Ronalds, A., 1836. The fly-fisher's entomology, illustrated by coloured representations of the natural and artificial insect and accompanied by a few observations and instructions relative to trout-and-grayling fishing. Longman, Rees, Orme, Brown, Green, and Longman, London, UK, 115 pp.

Ruddle, K., 1973. The human use of insects: examples from the Yukpa. Biotropica 5: 94-101. https://doi.org/10.2307/2989658

Rumbos, C.I. and Athanassiou, C.G., 2023. Mealworms for food and feed: are they only yellow? Journal of Insects as Food and Feed 9: 1409-1416. https://doi.org/10.1163/23524588-230912ED

Rumbos, C.I., Karapanagiotidis, I.T., Mente, E. and Athanassiou, C.G., 2019. The lesser mealworm *Alphitobius diaperinus*: a noxious pest or a promising nutrient source? Reviews in Aquaculture 11: 967-1463. https://doi.org/10.1111/raq.12300

Rutaisire, J., 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Uganda. In: Hasan, M.R., Hecht, T., De Silva, S.S. and Tacon, A.G.J. (eds.) Study and analysis of feeds and fertilizers for sustainable aquaculture development. FAO Fisheries Technical Paper. No. 497. FAO, Rome, Italy, pp. 471-487.

Ruxton, G.D. and Hansell, M.H., 2011. Fishing with a bait or lure: a brief review of the cognitive issues. Ethology 117: 1-9. https://doi.org/10.1111/j.1439-0310.2010.01848.x

Ryan, J.K., Jelen, P. and Sauer, W.C., 1983. Alkaline extraction of protein from spent honey bees. Journal of Food Science 48: 886-896. http://dx.doi.org/10.1111/j.1365-2621.1983.tb14923.x

Salmon, R.E. and Szabot, T.L., 1981. Dried bee meal as a feedstuff for growing turkeys. Canadian Journal of Animal Science. 61: 965-968. https://doi.org/10.4141/cjas81-118

Sanchez, M., 1996. Termites as chicken feed. Livestock Feed Resources within Integrated Farming Systems, Second FAO Electronic Conference on Tropical Feeds.

Sankara, F., Pousga, S., Dao, N.C.A., Gbemavo, D.S.J.C., Clottey, V.A., Coulibaly, K., Nacoulma, J.P., Ouedraogo, S. and Kenis, M., 2018. Indigenous knowledge and potential of termites as poultry feed in Burkina Faso. Journal of Insects as Food and Feed 4: 211-218. https://doi.org/10.3920/JIFF2017.0070

Sanou, A.G., Sankara, F., Pousga, S., Coulibaly, K., Nacoulma, J.P., Kenis, M., Clottey, V.A., Nacro, S., Somda, I. and Ouédraogo, I., 2018. Indigenous practices in poultry farming using maggots in western Burkina Faso. Journal of Insects as Food and Feed 4: 219-228. https://doi.org/10.3920/JIFF2018.0004

Santos, R.V. and Coimbra, C.E.A., 1984. Criação e comercialização de larvas de *Hermetia illucens* (Diptera: Stratiomydae) em uma comunidade do Distrito Federal. [Rearing and commercialization of *Hermetia illucens* (Diptera: Stratiomydae) larvae by a community in the Federal District, Brazil]. Ciência e Cultura 36: 2211-2215.

Savory, C.J., 1989. The importance of invertebrate food to chicks of gallinaceous species. Proceedings of the Nutrition Society 48: 113-133. https://doi.org/10.1079/PNS19890015

Sayed, W.A.A., Ibrahim, N.S., Hatab, M.H., Zhu, F. and Rumpold, B.A., 2019. Comparative study of the use of insect meal from *Spodoptera littoralis* and *Bactrocera zonata* for feeding Japanese quail chicks. Animals 9: 136. https://doi.org/10.3390/ani9040136

Schurr, K., 1972. Insects as a major protein source in sewage lagoon biomass usable as animal food. Proceedings of the North-Central Branch of the Entomological Society of America 27: 135-137.

Seidu, B., Bonsu, F.R.K., Kwenin, W.K.J., Tawiah, R. and Daniel, O.L., 2024. Utilization of shea caterpillar (*Cirina butyrospermi*) larvae meal as organic feed resource for broiler chicken. Journal of Journal of Experimental Agriculture International 46: 35-47.

Sestini, P. and Innocenti, A., 1987. Late asthmatic reactions due to larvae of *Calliphora erythrocephala* used as fishing bait. Allergologia et Immunopathologia. 15: 25-28.

Shaw, P.-C. and Mark, K.-K., 1980. Chironomid farming – a means of recycling farm manure and potentially reducing water pollution in Hong Kong. Aquaculture 21: 155-163. https://doi.org/10.1016/0044-8486(80)90024-1

Sheikh, I., Banday, M., Baba, I., Adil, S., Nissa, S.S., Zaffer, B. and Bulbul, K., 2018. Utilization of silkworm pupae meal as an alternative source of protein in the diet of livestock and poultry: a review. Journal of Entomology and Zoology Studies 6: 1010-1016.

Shi, B.L., Li, D.F., Piao, X.S. and Yan, S.M., 2005. Effects of chitosan on growth performance and energy and protein utilisation in broiler chickens. British Poultry Science 46: 516-519. https://doi.org/10.1080/00071660500190785

Shibata, Y., Foster, L., Metzger, W. and Myrvik, Q., 1997. Alveolar macrophage priming by intravenous administration of chitin particles, polymers of N-acetyl-D-glucosamine, in mice. Infection and Immunity 65: 1734-1741. https://doi.org/10.1128/iai.65.5.1734-1741

Siddiqui, S.A., Brunner, T.A., Tamm, I., Van der Raad, P., Patekar, G., Alim Bahmid, N., Aarts, K. and Aman, P., 2023. Insect-based dog and cat food: a short investigative review on market, claims and consumer perception. Journal of Asia-Pacific Entomology 26: 102020. https://doi.org/10.1016/j.aspen.2022.102020

Silow, C.A., 1983. Notes on Ngangela and Nkoya Ethnozoology. Ants and termites. Etnologiska Studier 36, Goeteborg, Sweden, 177 p.

Siracusa, A., Bettini, P., Bacoccoli, R., Severini, C., Verga, A. and Abbritti, G., 1994. Asthma caused by live fish bait. The Journal of Allergy and Clinical Immunology 93: 424-430. https://doi.org/10.1016/0091-6749(94)90350-6

Smith, R., Hauck, R., Macklin, K., Price, S., Dormitorio, T. and Wang, C., 2021. A review of the lesser mealworm beetle (*Alphitobius diaperinus*) as a reservoir for poultry bacterial pathogens and antimicrobial resistance. World's Poultry Science Journal 78: 197-214. https://doi.org/10.1080/00439339.2022.2003172

Sogbesan, A.O. and Ugwumba, A.A.A., 2008. Nutritional Evaluation of Termite (*Macrotermes subhyalinus*) Meal as Animal Protein Supplements in the Diets of *Heterobranchus longifilis* (Valenciennes, 1840) Fingerlings. Turkish Journal of Fisheries and Aquatic Sciences 8: 149-157.

Sogbesan, O., Ajuonu, N., Musa, B.O. and Adewole, A.M., 2006. Harvesting techniques and evaluation of maggot meal as animal dietary protein source for *Heteroclarias* in outdoor concrete tanks. World Journal of Agricultural Sciences 2: 394-402.

St-Hilaire, S., Sheppard, C., Tomberlin, J.K., Irving, S., Newton, L., McGuire, M.A., Mosley, E.E., Ronald, W., Hardy, R.E. and Sealey, W., 2007. Fly prepupae as a feedstuff for rainbow trout, *Oncorhynchus mykiss*. Journal of the World Aquaculture Society 38: 59-67. https://doi.org/10.1111/j.1749-7345.2006.00073.x

Stockley, R.A., Hill, S.L. and Drew, R., 1982. Asthma associated with a circulating IgG to *Calliphora* maggots. Clinical Allergy 12: 151-155. https://doi.org/10.1111/j.1365-2222.1982.tb01634.x

Surendra, K.C., Tomberlin, J.K., Van Huis, A., Cammack, J.H., Heckmann, L.-H.L. and Khanal, S.K., 2020. Rethinking organic wastes bioconversion: Evaluating the potential of the black soldier fly (*Hermetia illucens* (L.)) (Diptera: Stratiomyidae) (BSF). Waste Management 117: 58-80. https://doi.org/10.1016/j.wasman.2020.07.050

Sutton, M.Q., 1990. Insect resources and plio-pleistocene hominid evolution. In: Posey, D.A. and Overal, W.L. (eds.) Ethnobiology: implications and applications. Vol. I. Proceedings of the First International Congress of Ethnobiology, 1988, Belém. Museu Paraense Emìlio Goeldi, Belém, Brazil, pp. 195-207.

Suzuki, S. and Park, J., 2018. Consumer evaluation of healthy, unpleasant-tasting food and the post-taste effect of positive information. Food Quality and Preference 66: 107-110. https://doi.org/10.1016/j.foodqual.2018.01.006

Świątkiewicz, S., Arczewska-Włosek, A., Krawczyk, J., Puchała, M. and Józefiak, D., 2013. Effects of selected feed additives on the performance of laying hens given a diet rich in maize dried distiller's grains with solubles (DDGS). British Poultry Science 54: 478-485. http://dx.doi.org/10.1080/00071668.2013.797563

Téguia, A., Mpoame, M. and Mba, J.A.O., 2002. The production performance of broiler birds as affected by the replacement of fish meal by maggot meal in the starter and finisher diets. Tropicultura 4: 187-192.

Teng, Q., Hu, X.-F., Cheng, C., Luo, Z., Luo, F., Xue, Y., Jiang, Y., Mu, Z., Liu, L. and Yang, M., 2016. Ecological effects of rice-duck integrated farming on soil fertility and weed and pest control. Journal of Soils and Sediments 16: 2395-2407. https://doi.org/10.1007/s11368-016-1455-9

Teotia, J.S. and Miller, B.F., 1973. Fly pupae as a dietary ingredient for starting chicks. Poultry Science 52: 1830-1835. https://doi.org/10.3382/ps.0521830

Teotia, J.S. and Miller, B.F., 1974. Nutritive content of house fly pupae and manure residue. British Poultry Science 15: 177-182. https://doi.org/10.1080/00071667408416093

Thirumalaisamy, G., Muralidharan, J., Senthilkumar, S., Sayee, R.H. and Priyadharsini, M., 2016. Cost-effective feeding of poultry. International Journal of Science, Environment 5: 3997-4005.

Thompson, W.R., 1956. Book review – Fishing with natural insects. The Canadian Entomologist 88: 563-564. https://doi.org/10.4039/Ent88563-9

Tomberlin, J.K., Picard, C.J., Jordan, H.R., Preyer, C., Warburton, C., Crowley, P., Zheng, R., Boulanger, F.X., Banks, I., Lefranc, M., Zorrilla, M.J., Olson, G., Aid, G., Fluker, D., Bench, B.J., Teo, M., Richards, C.S., Jones, C., Gonzalez, J. and Eljendy, M., 2022. Government and industry investment plays crucial role in further establishment, evolution, and diversification of insect agriculture: a case example from the United States. Journal of Insects as Food and Feed 8: 109-111. https://doi.org/10.3920/JIFF2022.x001

Tran, G., Heuzé, V. and Makkar, H.P.S., 2015. Insects in fish diets. Animal Frontiers 5: 37-44. https://doi.org/10.2527/af.2015-0018

Valdés, F., Villanueva, V., Durán, E., Campos, F., Avendaño, C., Sánchez, M., Domingoz-Araujo, C. and Valenzuela, C., 2022. Insects as feed for companion and exotic pets: a current trend. Animals 12: 1450. https://doi.org/10.3390/ani12111450

Van der Heide, M.E., Nørgaard, J.V. and Engberg, R.M., 2021. Performance, nutrient digestibility and selected gut health parameters of broilers fed with black soldier fly, lesser mealworm and yellow mealworm. Journal of Insects as Food and Feed 7: 1011-1022. https://doi.org/10.3920/JIFF2020.0150

Van Huis, A., 2017a. Chapter 3.1. Introducing small production systems for edible insects. In: Van Huis, A. and Tomberlin, J. (eds.) Insects as food and feed: from production to consumption. Wageningen Academic Publishers, Wageningen, the Netherlands, 448 pp. https://doi.org/10.3920/978-90-8686-849-0

Van Huis, A., 2017b. Cultural significance of termites in sub-Saharan Africa. Journal of Ethnobiology and Ethnomedicine 13: 8. https://doi.org/10.1186/s13002-017-0137-z

Van Huis, A., 2018. Chapter 11 – Insects as Human Food. In: Nóbrega Alves, R.R. and Albuquerque, U.P. (eds.) Ethnozoology. Academic Press, Cambridge, MA, USA, pp. 195-213. https://doi.org/10.1016/B978-0-12-809913-1.00011-9

Van Huis, A., 2021a. Cultural significance of beetles in sub-Saharan Africa. Insects 12: 368. https://doi.org/10.3390/insects12040368

Van Huis, A., 2021b. Harvesting desert locusts for food and feed may contribute to crop protection but will not suppress upsurges and plagues. Journal of Insects as Food and Feed 7: 245-248. https://doi.org/10.3920/JIFF2021.x003

Van Huis, A. and Gasco, L., 2023. Insects as feed for livestock production. Science 379: 138-139. https://doi.org/10.1126/science.adc9165

Van Huis, A., Itterbeeck, J.V., Klunder, H., Mertens, E., Halloran, A., Muir, G. and Vantomme, P., 2013. Edible insects: future prospects for food and feed security. FAO Forestry Paper 171. Food and Agriculture Organization of the United Nations, Rome, Italy and Wageningen University and Research Centre, Wageningen, the Netherlands, 187 pp.

Van Zanten, H.H.E., Simon, W., Van Selm, B., Wacker, J., Maindl, T.I., Frehner, A., Hijbeek, R., van Ittersum, M.K. and Herrero, M., 2023. Circularity in Europe strengthens the sustainability of the global food system. NatuRE Food 4: 320-330. https://doi.org/10.1038/s43016-023-00734-9

Veldkamp, T., Belghit, I., Chatzfiotis, S., Mastoraki, M., Jansman, A.J.M., Radhakrishnan, G., Schiavone, A., Smetana, S. and Gasco, L., 2023. The role of insects in novel sustainable animal production systems. In: Arsenos, G. and Giannenas, I. (eds.) Sustainable use of feed additives in livestock: novel ways for animal production. Springer, Cham, Switzerland, pp. 137-172. https://doi.org/10.1007/978-3-031-42855-5_7

Veldkamp, T. and Bosch, G., 2015. Insects: a protein-rich feed ingredient in pig and poultry diets. Animal Frontiers 5: 45-50. https://doi.org/10.2527/af.2015-0019

Veldkamp, T., Dong, L., Paul, A. and Govers, C., 2022. Bioactive properties of insect products for monogastric animals – a review. Journal of Insects as Food and Feed 8: 1027-1040. https://doi.org/10.3920/JIFF2021.0031

Veldkamp, T. and Eilenberg, J., 2018. Insects in European feed and food chains. Journal of Insects as Food and Feed 4: 143-145. https://doi.org/10.3920/JIFF2018.x006

Veldkamp, T., Fels, H.J.v.d., Meijer, N.P. and Octavia, M., 2020. Introduction to the EU H2020 project SUSINCHAIN (SUStainble INsect CHAIN). Journal of Insects as Food and Feed 6(Supplement 1): 43-43. https://doi.org/10.3920/JIFF2020.S1

Veldkamp, T. and Vernooij, A.G., 2021. Use of insect products in pig diets. Journal of Insects as Food and Feed 7: 781-793. https://doi.org/10.3920/JIFF2020.0091

Vorsters, A., Aminou, T. and Demey, F., 1994. Récolte de termites pour l'aviculture à Songhai (Bénin). Cahiers Agricultures 3: 265-266.

Wainwright, M., Laswd, A. and Alharbi, S., 2007. When maggot fumes cured tuberculosis. Microbiologist 8: 33-35.

Wang, J.P., Yoo, J.S., Kim, H.J., Lee, J.H. and Kim, I.H., 2009. Nutrient digestibility, blood profiles and fecal microbiota are influenced by chitooligosaccharide supplementation of growing pigs. Livestock Science 125: 298-303. https://doi.org/10.1016/j.livsci.2009.05.011

Williams, D.D., Williams, S.S. and Van Huis, A., 2021. Can we farm aquatic insects for human food or livestock feed? Journal of Insects as Food and Feed 7: 121-127. https://doi.org/10.3920/JIFF2021.x002

Yan, L., Lee, J., Meng, Q.W., Ao, X. and Kim, I.-S., 2010. Evaluation of dietary supplementation of delta-aminolevulinic acid and chito-oligosaccharide on production performance, egg quality and hematological characteristics in laying hens. Asian-Australasian Journal of Animal Sciences 23: 1028-1033. https://doi.org/10.5713/ajas.2010.90639