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THE POTENTIAL OF INSECTS AS ALTERNATIVE ANIMAL PROTEIN SOURCE FOR LIVESTOCK FEEDING

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ABSTRACT

The livestock industry as an important component of general agriculture is a key contributor to economic growth and development of any nation. In addition to having the capacity for earning revenue for the governments, it provides employment, food, farm energy, manure, fuel and transport. Currently, important protein ingredients for animal feed are fish meal, processed animal proteins and soybean meal. However, in the European Union the use of processed animal proteins in animal feed is prohibited due to the TSE legislation, globally land availability for soya cultivation is limited, while marine overexploitation has reduced the abundance of small pelagic forage fish from which fish meal and fish oil is derived. The growing scarcity of resources to produce these increasingly demanded ingredients has doubled prices during the last five years, while it already represents 60-70% of production costs. So, alternative (animal) protein sources for livestock and aquaculture are urgently needed.
Insects are such an alternative animal protein source, which can sustainably reared on organic side streams. Reasons are that they have a favorable feed conversion efficiency, likely because they are cold-blooded. Insects contain between 30% and 70% protein on a dry matter basis. The protein content of the insect species is within the soybean/fish meal range and fat content is higher especially compared to (defatted) soybean meal. This review, however highlighted the environmental, health, livelihood and social benefits of insects. Recent efforts in feeding livestock, challenges limiting the use of insects as feed ingredients and moreover, the strategies for commercial production of insects as feed ingredients just to mention a few of the potentials of using insects for feeding livestock.

KEYWORDS: Potentials, Insects, Feeding, Livestock

INTRODUCTION

The livestock industry as an important component of general agriculture is a key contributor to economic growth and development of any nation. In addition to having the capacity for earning revenue for the governments, it provides employment, food, farm energy, manure, fuel and transport (Philips, 2014). As Fakoya (2015) has succinctly argued, livestock, especially ruminant production, is the most efficient user of uncultivated land and contribute evidently to crop production. Efficient crop-livestock integration systems have the tendency of allowing nutrients to be recycled more effectively on the farm thereby enhancing crops' yield. Under such a system livestock can be fed on crop residues, like straw, damaged fruits and grains, as well as other products that would have posed a major waste disposal problem (Fakoya, 2015).

Livestock systems occupy about 30 per cent of the planet's ice-free terrestrial surface area (Metha *et al.* 2015) and are a significant global asset with a value of at least $1.4 trillion. The livestock sector is increasingly organized in long market chains that employ at least 1.3 billion people globally and directly support the livelihoods of 600 million poor smallholder farmers in the developing world (Thornton et al. 2022). Keeping livestock is an important risk reduction strategy for vulnerable communities, and livestock are important providers of nutrients and traction for growing crops in smallholder systems. Livestock products contribute 17 per cent to kilocalorie consumption and 33 per cent to protein consumption globally, but there are large differences between rich and poor countries (Rosegrant et al. 2016).
Livestock systems have both positive and negative effects on the natural resource base, public health,

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social equity and economic growth (World Bank, 2009). Currently, livestock is one of the fastest growing agricultural subsectors in developing countries. Its share of agricultural GDP is already 33 per cent and is quickly increasing. This growth is driven by the rapidly increasing demand for livestock products, this demand being driven by population growth, urbanization and increasing incomes in developing countries (Delgado 2016).

The global livestock sector is characterized by a dichotomy between developing and developed countries. Total meat production in the developing world tripled between 1980 and 2002, from 45 to 134 million tons (World Bank, 2022). Much of this growth was concentrated in countries that experienced rapid economic growth, particularly in East Asia, and revolved around poultry and pigs. In developed countries, on the other hand, production and consumption of livestock products are now growing only slowly or stagnating, although at high levels. Even so, livestock production and merchandizing in industrialized countries account for 53 per cent of agricultural GDP (World Bank 2022). This combination of growing demand in the developing world and stagnant demand in industrialized countries represents a major opportunity for livestock keepers in developing countries, where most demand is met by local production, and this is likely to continue well into the foreseeable future. At the same time, the expansion of agricultural production needs to take place in a way that allows the less well-off to benefit from increased demand and that moderates its impact on the environment.

In 2011, the world compound feed production was an estimated 870 million tonnes and the turnover of global commercial feed manufacturing generated an estimated annual turnover and sales value equivalent to US$350 billion worldwide (http://www.ifif.org/). The UN Food and Agricultural Organisation (FAO) estimates that the world will have to produce ca. 70% more food by 2050 (High-Level Expert, 2016). The mobile advertising as Insecta. The body is divided into 3 sections: head, thorax, abdomen. They have 6 legs attached to the thorax, they usually have wings, also attached to the thorax. In insects such as beetles, the elytrae (= hard wings) cover the flying wings and lie flat against the abdomen at rest (Land Care Research, 2016).

Insects are arthropods. All animals in the phylum Arthropoda have exoskeletons, segmented bodies, and at least three pairs of legs. Other classes that belong to the phylum Arthropoda include: Arachnida (spiders), Crustacea (crabs), and Myriopoda (millipedes and centipedes). Insects are such an alternative animal protein source, which can sustainably reared on organic side streams. Reasons are that they have a favorable feed conversion efficiency, likely because they are cold-blooded. Insects contain between 30% and 70% protein on a dry matter basis. Table 1 shows protein and fat composition of larvae for three insect species in comparison to fishmeal and defatted soybean meal. The protein content of the insect species is within the soybean/fish meal range and fat content is higher especially compared to (defatted) soybean meal Global Feed : The Global Feed Industry (2022).

Table 1:Crude protein and fat content (dry matter basis) of larvae of three insect species compared to fish meal and (defatted) soybean meal

Protein source	Crude protein (%)	Crude fat (%)
Hermetiaillucens(Black soldier fly1)	35-57	**35**
Muscadomestica(Common housefly1)	43-68	**4-32**
Tenebriomolitor(Yellow mealworm1)	44-69	**23-47**
Fishmeal2	61-77	**11-17**
Soybean meal (defatted)2	49-56	**3**

Source: CVB, 2007.

Efficient use of insects can close the loop in a sustainable circular economy, as shown in Figure 1. The figure indicates the possibility of insects to be used in feed as one of the options. A key element in successful introduction of insects in the feed chain is that multiple quality aspects need to be taken into account. In this respect we refer to the extended quality triangle (Luning and Marcelis 2009), modified from Noori ome : Global Feed : The Global Feed Industry.Animal feeds play a leading role in the global food industry, enabling economic production of animal proteins throughout the world. Feed is the largest and most important component to ensuring safe, abundant and affordable animal proteins which identifies three quality dimensions linked to the product itself. These three elements being insect quality as such, insect availability, and costs are all considered to be crucial for a successful introduction of insect protein in feed and are therefore included in this report. The three quality aspects linked to the organisation, namely reliability, flexibility and service are not considered to be critical in this phase and are thus not taken into account (https://ifif.org/global-feed/industry/).

More in detail, the technical consultation meeting entitled "*Assessing the Potential of Insects as Food and Feed in assuring Food Security"* held from 23-25 January 2012 at FAO Rome(http://www.fao.org/forestry/edibleinsects/74848/en/) considered as major challenges to use insects as feed: selecting suitable insect species and strains, finding cheap rearing substrate (if possible by utilizing organic waste side-streams, but assuring feedstock safety when rearing insects on organic waste and manure), managing diseases and setting up sanitation procedures, producing a constant supply of high quality insects (including quality assurance), developing innovative and cost-effective production systems, increasing automation/mechanization, safeguarding animal welfare (ethical concerns), establishing a regulatory framework, and elaborating an industrial code of practices/standards. All these aspects can be linked to one or more steps in the feed chain and will be worked out further in this document.

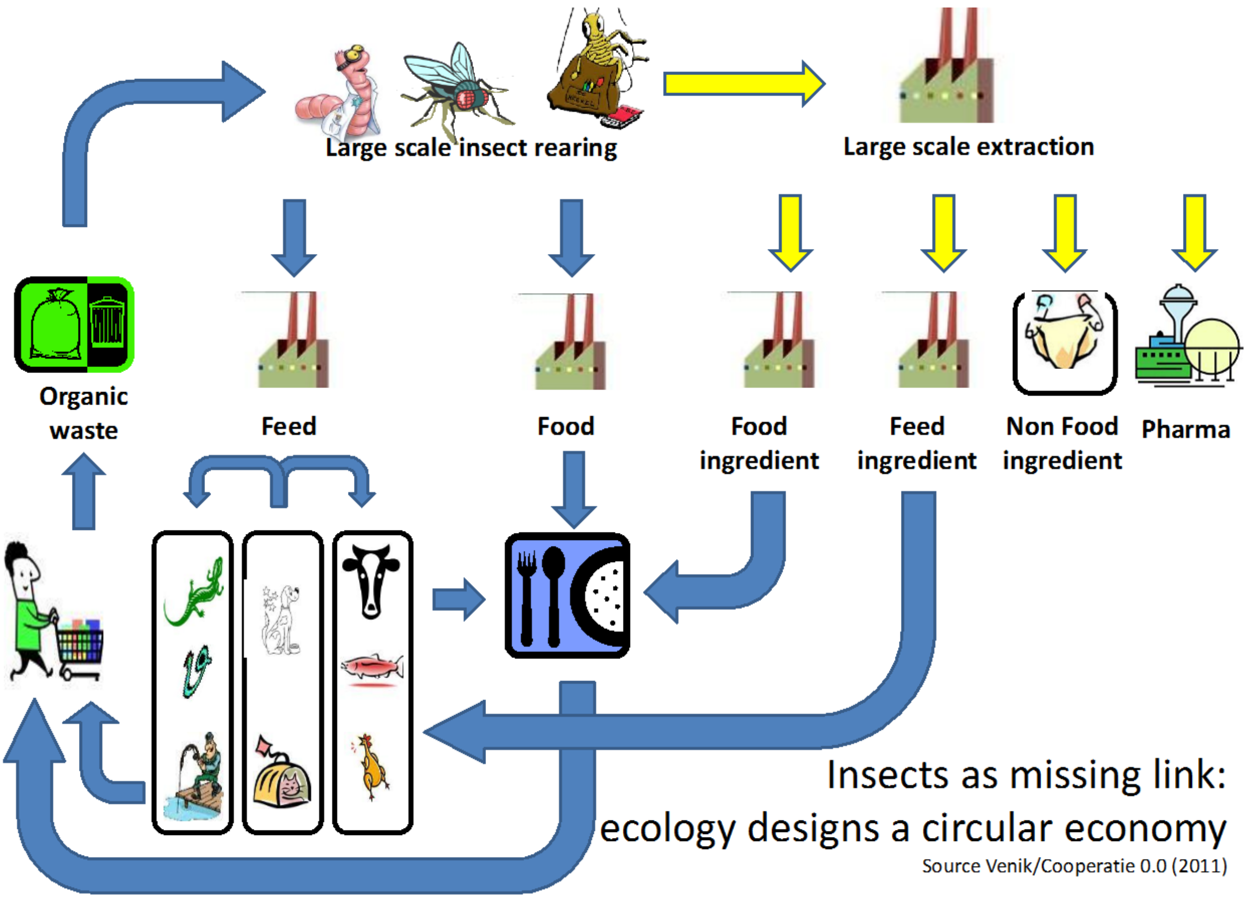

Figure 1 How to use insects in a circular economy

FAO (2013) in a report stated that insects have being contributing either directly or indirectly to human nutrition. According to them, the use of insects as food and feed has many environmental, health andsocial/livelihood benefits. For example:

Environmental benefits

➢ Insects have a high feed conversion efficiency because they are cold-blooded. Feed-to-meat conversion rates (how much feed is needed to produce a1 kg increase in weight) vary widely depending on the class of the animal and the production practices used, but nonetheless insects are extremely efficient. On average, insects can convert 2 kg of feed into 1 kg of insect mass, whereas cattle require 8 kg of feed to produce 1 kg of body weight gain (Ifeanyi et al, 2021).

➢ The production of greenhouse gases by most insects is likely to be lower than that of conventional livestock. For example, pigs produce 10–100 times more greenhouse gases per kg of weight than mealworms.

➢ Insects can feed on bio-waste, such as food and human waste, compost and animal slurry, and can transform this into high-quality protein that can be used for animal feed.

➢ Insects use significantly less water than conventional livestock. Mealworms, for example, are more drought-resistant than cattle (FAO, 2016).

➢ Insect farming is less land-dependent than conventional livestock farming.

Health benefits

The nutritional content of insects depends on their stage of life (metamorphic stage), habitat and diet. However, it is widely accepted that:

➢ Insects provide high-quality protein and nutrients comparable with meat and fish. Insects are particularly important as a food supplement for under nourished children because most insect species are high in fatty acids (comparable with fish). They are also rich in fibre and micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium and zinc (Kuyper *et al.* 2013).

➢ Insects pose a low risk of transmitting zoonotic diseases (diseases transmitted from animals to humans) such as like H1N1 (bird flu) and BSE (mad cow disease).

Livelihood and social benefits

- Insect gathering and rearing can offer important livelihood diversification strategies. Insects can be directly and easily collected in the wild. Minimal technical or capital expenditure is required for basic harvesting and rearing equipment (Arnold *et al.* 2013).
- Insects can be gathered in the wild, cultivated, processed and sold by the poorest members of society, such as women and landless people in urban and rural areas. These activities can directly improve diets and provide cash income through the selling of excess production as street food (FAO, 2013).
- Insect harvesting and farming can provide entrepreneurship opportunities in developed, transitional and developing economies.
- Insects can be processed for food and feed relatively easily. Some species can be consumed whole. Insects can also be processed into pastes or ground into meal, and their proteins can be extracted.

According to FAO (2013), it is estimated that insects form part of the traditional diets of at least 2 billion people. More than 1 900 species have reportedly been used as food. Insects deliver a host of ecological services that are fundamental to the survival of humankind. They also play an important role as pollinators in plant reproduction, in improving soil fertility through waste bioconversion, and in natural biocontrol for harmful pest species, and they provide a variety of valuable products for humans such as honey and silk and medical applications such as maggot therapy. In addition, insects have assumed their place in human cultures as collection items and ornaments and in movies, visual arts and literature. Globally, the most commonly consumed insects are beetles (Coleoptera) (31 percent), caterpillars (Lepidoptera) (18 percent) and bees, wasps and ants (Hymenoptera) (14 percent). Following these are grasshoppers, locusts and crickets (Orthoptera) (13 percent), cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera) (10 percent), termites (Isoptera) (3 percent), dragonflies (Odonata) (3 percent), flies (Diptera) (2 percent) and other orders (5 percent). Example isolate (FAO, 2016).

Biology of insects and stages of development

All insects begin their development as eggs produced by the adult female. A few species, such as aphids, give birth to live young, but the young are actually hatched from eggs carried inside the mother. After egg hatch, insects grow in a series of distinct stages. Periodically, the insect sheds its exoskeleton (molt) and expands the soft new exoskeleton by inhaling air. In a few hours the new exoskeleton hardens and there is no further change in body size until the following molt (Elizabeth and Geraldine, 2018). Through this process the insect is able to expand in size despite being encapsulated in an external skeleton. In some cases, such as many soft bodied larvae, the exoskeleton is soft, allowing limited expansion between molts, but the insect must still molt to complete development. In many insect species, there are also specialized molting events in which the insect not only sheds its old exoskeleton, but forms a new exoskeleton with new features. All growth ceases following the final molt to the adult stage of the insect. An adult insect will not increase in size as it ages. The specialized molting process in which the insect undergoes a major change in form is called metamorphosis. The kinds of change vary among different insect groups. Two general types of development predominate: simple metamorphosis (hemimetabolous insects), and complete metamorphosis (holometabolous insects) (Jens *et al.* 2019).

Several of the more primitive orders of insects undergo no distinct metamorphosis (ametabolous insects). The Collembola and Thysanura are examples, developing directly to the adult without major changes in structure.

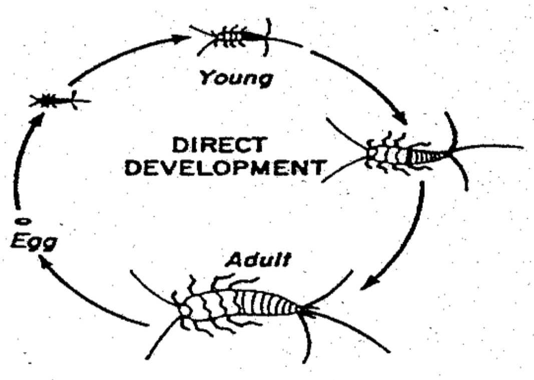

Fig. 1 Gradual growth without metamorphosis displayed in growth of silverfish.

Source: (Jens *et al.* 2019).

Insects undergoing simple metamorphosis have three basic life stages: egg, nymph, and adult. The nymphs typically pass through three to five instars, molting between each to attain the larger size of the next in star. Nymphs and adults often live in the same habitat. The principal changes occurring during metamorphosis are changes in body proportions, sexual maturity, and the development of wings. Examples of insects that undergo simple metamorphosis includegrasshoppers and crickets (Orthoptera), earwigs(Dermaptera), cockroaches (Blatteria), "true" bugs (Hemiptera), and aphids and their relatives (Homoptera) (Jens *et al.* 2013).

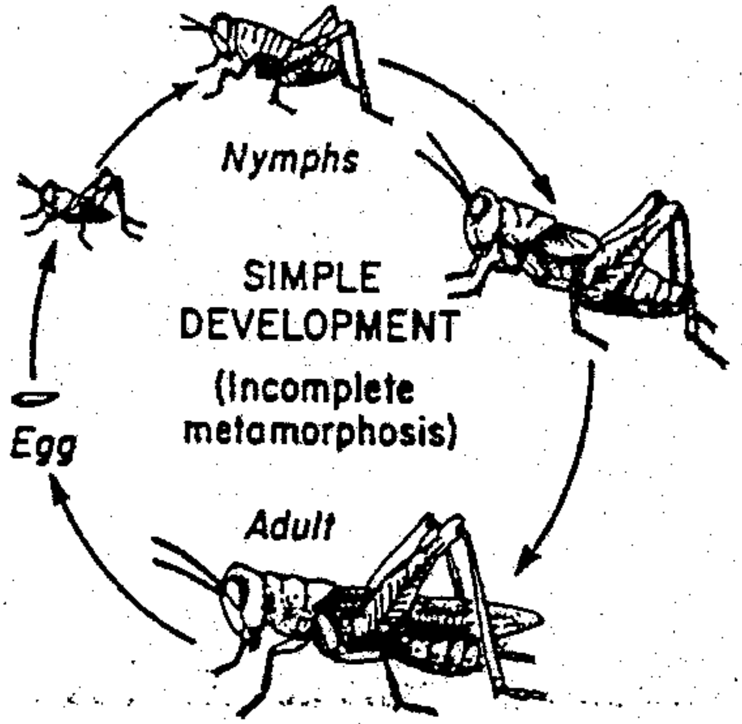

Fig. 2. Simple metamorphosis displayed in growth of grasshoppers.

Source: (Jens *et al.* 2019).

Insects that undergo complete metamorphosis pass through four basic life stages: egg, larva, pupa, and adult. Caterpillars, maggots, and grubs are common examples of larvae. During the larval stage there maybe three to seven instars, all of which usually are active, and often ferocious feeders. The pupal stage(e.g., cocoon, puparia, chrysalid) is a non-feeding stage that follows the specialized molt from the larval stage. During the pupal stage, many physiological and morphological changes occur. Internally, the insect is going through the process of changing to the adult form. During the final molt, the adult emerges from the hardened exoskeleton of the pupal case. Adults are usually winged and may differ from the larvae in a number of ways including type of legs, mouthparts and feeding habits. Adults of insects undergoing complete metamorphosis are very different in form from the larvae. They may be found in habitats similar to the larvae, such as some beetles, or in very different habitats than the larvae, such as bees and butterflies. Insects with complete metamorphosis include butterflies and moths (Lepidoptera), beetles (Coleoptera), "true" flies (Diptera), and lace wings (Neuroptera). The larval stage tends to specialize in feeding. The adult stage specializes in dispersal and reproduction, but may feed and cause economic damage as well.

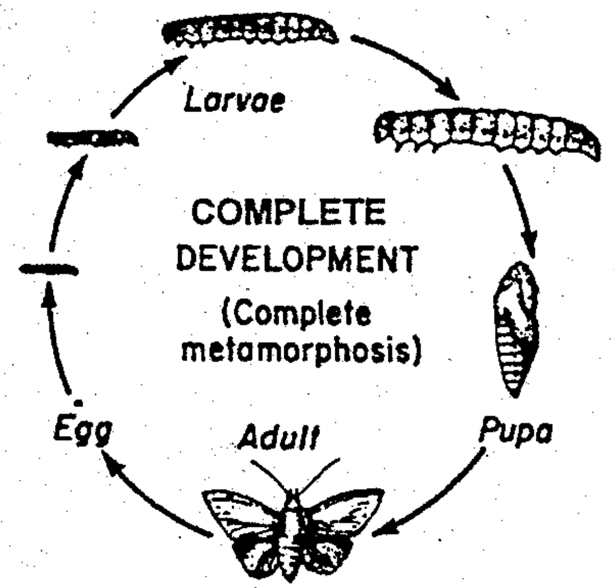

Fig. 3. Complete metamorphosis displayed in growth of moths.

Source: (Jens *et al.* 2019).

SOCIAL ECONOMIC BENEFITS OF INSECTS

Insect gathering and rearing as mini livestock at the household level or industrial scale can offer important livelihood opportunities for people in both developing and developed countries. In developing countries, some of the poorest members of society, such a women and landless dwellers in urban and rural areas, can easily become involved in the gathering, cultivation, processing and sale of insects. These activities can directly improve their own diets and provide cash income through the selling of excess production as street foods. Insects can be directly and easily collected from nature or farmed with minimal technical or capital expenditure (i.e. for basic harvesting/rearing equipment). Rearing insects may also require minimal land or market introduction efforts, as insects already form part of some local food cultures (Rohanie, 2014).

Protein and other nutritional deficiencies are typically more widespread in disadvantaged segments of society and during times of social conflict and natural disaster. Because of their nutritional composition, accessibility, simple rearing techniques and quick growth rates, insects can offer a cheap and efficient opportunity to counter nutritional insecurity by providing emergency food and by improving livelihoods and the quality of traditional diets among vulnerable people (Honor, 2016).

Gathering and farming insects can offer employment and cash income, either at the household level or in larger, industrial-scale operations. In developing countries in Southern and Central Africa and Southeast Asia, where demand for edible insects exists and where it is relatively easy to bring insects to market, the process of insect gathering, rearing and processing into street foods or for sale as chicken and fish feed is easily within reach of small-scale enterprises. With only a few exceptions, international trade in insects for food is in significant. The trade that does exist to developed countries is often driven by demand from immigrant communities or because of the development of niche markets that sell exotic foods. Border trade in edible insects is significant, mainly in Southeast Asia and Central Africa.

Commonly consumed insects and their nutritional values

Among the most promising species for industrial feed production are black soldier flies, common housefly larvae, silkworms and yellow mealworms. Grasshoppers and termites are also viable, but to a lesser extent. To date, these species are the most studied and account for the majority of the literature.

Black soldier flies

Black soldier flies (*Hermetiaillucens*) (Diptera: Stratiomyidae) are found in abundance and naturally occur around the manure piles of large poultry, pigs and cattle. For this reason, they are known as latrine larvae. The larvae also occur in very dense populations on organic wastes such as coffee bean pulp, vegetables, distillers' waste and fish offal (fish processing by products). They can be used commercially to solve a number of environmental problems associated with manure and other organic waste, such as reducing manure mass, moisture content and offensive odours. At the same time they provide high-value feedstuff for cattle, pig, poultry and fish (Newton *et al.*, 2005). The adult black soldier fly, moreover, is not attracted to human habitats or foods and for that reason is not considered a nuisance. The high crude fat content of black soldier flies can be converted to biodiesel: 1 000 larvae growing on 1 kg of cattle manure, pig manureand chicken manure produce 36 g, 58 g and 91 g, respectively, of biodiesel (Li *et al.*,2011).

Black soldier flies as animal feed

The use of black soldier fly pre pupae as animal feed should be seriously considered, not least for their reduced environmental footprint (Newton *et al.*, 1977; Sheppard *et al.*, 1994). Dried black soldier fly pre pupae contain 42 percent protein and 35 percent fat(on a dry matter basis) (Newton *et al.*, 1977). Live pre pupae consist of 44 percent dry matter and can easily be stored for long periods. As a component of a complete diet, they have been found to support good growth in chicks (Hale, 1973), pigs (Newton*et al.*, 1977) rainbow trout (*Oncorhynchusmykiss*) (St-Hilaire*et al.*, 2007), channel catfish (*Ictaluruspunctatus*) (Pimentel *et al.*, 2004) and blue tilapia (*Oreochromisaureus*)(Sheppard *et al.*, 2008). In the case of rainbow trout, the larvae can replace 25 percent of fish meal use and 38 percent of fish oil use. Instead of feeding insects to fish, insects can be reared on fish. Among the organic waste products, fish offal (entrails, etc.) can be fed to larvae. Compared with larvae fed on manure, lipid content increased by 30 percent and omega-3 fatty acids increased by 3 percent; both increases occurred within 24 hours(St-Hilaire*et al.*, 2007).

Common housefly larvae

Maggots – the larvae of the common housefly (*Muscadomestica*) – develop predominantlyin tropical environments. Maggots are important sources of animal proteins for poultry: they have a dry matter of 30 percent of their total wet larval mass, 54 percent of which is crude protein. Maggots can be offered fresh, but for intensive farming they are more convenient as a dry product in terms of storage and transport. Studies have shown that maggot meal could replace fishmeal in the production of broiler chickens (Téguia*et al.*,2002; Hwangbo *et al.*, 2009). At the same time, maggot production can contribute to alleviating manure accumulation.

In rural Africa, maggots are natural food items for scavenging poultry. In Nigeria, for example, maggot production could provide an excellent source of animal protein for local poultry farms. Maggots are already fed live to chickens in Togo (Ekoue and Hadzi,2000) and Cameroon (Téguia, Mpoame and Okourou, 2002). In South Korea, Hwangbo*et al.* (2009) explored the contribution of maggots to the meat quality and growth performance of broiler chickens and found that feeding diets containing 10–15 percent maggots can improve the carcass quality and growth performance of broiler chickens.

In Nigeria, Awonyi, Adetuyi and Akinyosoye (2004) evaluated the replacement of fish meal with maggot meal and found that diets in which 25 percent of fishmeal was replaced with maggot meal were most efficient in terms of average weekly weight gain and protein efficiency rate.

At nine weeks, the live, dressed and eviscerated weights of the chickens, as well as the relative length, breadth and weights of the pectoral and gastrocnemius muscles, were not significantly affected by replacement with maggot meal. It was concluded that maggot meal is an inexpensive partial substitute for fish meal in broiler-chick feeding.

The inclusion of maggot meal in livestock diets, however, raises concerns because common knowledge suggests that, in its adult form, *Muscadomestica*is widely involved in the transmission of disease. The larvae develop in manure and decaying filth; for thisreas on, maggot meal in livestock diets raises bacteriological and mycological concerns. In Nigeria, Awoniyi, Adetuyi and Akinyosoye (2004) investigated fresh and nine month-old stored samples of dried, milled housefly larvae for the presence of microbes to determine their suitability for inclusion in livestock diets. Their main conclusion was that stored maggot meal is prone to deterioration by fungi and bacteria if the moisture content is too high (in their study 23 percent, while the limit was 12 percent). They recommended drying to 4–5 percent moisture to minimize bacterial activity. After processing, protection from moisture absorption can be achieved by waterproof bagging (with cellophane or nylon) and heat-sealing.

Termites

Termites caught in the wild can be used to catch fish and birds. Silow (1983) reported from Zambia the use of snouted termites (*Trinervitermes*spp.) 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 mass for hours. However, rearing termites is very difficult and should not be recommended, also bearing in mind their high emissions of methane (Hackstein and Stumm, 1994).

SOR-Mite (protein-enriched sorghum porridge)

The "developing solutions for developing countries" competition, organized by the Institute of Food Technologists, promotes the application of food science and technology and the development of new products and processes with the aim of improving the quality of life of people in developing countries. The first prize of the competition, awarded during the Annual Food Expo in Anaheim, United States, in June 2009, went to the SOR-Mite project, a sorghum mixture enriched with termites. The nutritionally weak grain, frequently consumed in many African countries, is low in proteins and fats and lacks several essential amino acids, such as lysine. For this reason, fortifying the grain with highly nutritious flying termites (*Macrotermes*species), easily gathered at the start of the rainy season, makes sense. The fermented mixture can be consumed as porridge at breakfast, lunch or dinner, depending on local preferences. Both raw materials are easily obtained locally (Institute of Food Technologists, 2011).

Termite crackers and muffins in Kenya

In the Lake Victoria region in East Africa, edible insects such as termites (Isoptera: Termitidae) and lake flies (Diptera, Chaoboridae, Chironomidae and Ephemeroptera) are abundant and provide important nutrition for both humans and livestock. Although their use is limited by their seasonal availability and high perishability, processing them with conventional cooking methods could extend their shelf life considerably and contribute to promoting entomophagy throughout the region. In a recent study carried out in the cross-border ecosystem, locally available insects were roasted, sundried, ground and mixed with other ingredients and processed into food products. Termite-based and lake fly-based crackers, muffins, meatloaf and sausages were found to have especially high potential for commercialization (Ayieko, Oriamo and Nyambuga, 2010).

Buqadilla

Buqadilla is an innovative snack under development for the Dutch market. It is a spicy Mexican leguminoceous food product made of chickpeas and lesser mealworms (40 percent). It was well received in several restaurants and canteens, where the product was tested, for its taste and smooth structure. The sustainable, healthy and exotic snack is an example of an accessible and culturally acceptable way for Western consumers to experience and appreciate edible insects as food (van Huis, van Gurp and Dicke, 2012).

Crikizz

Crikizz is another example of European products made with insects. Developed byYnsect and French students, Crikizz are spicy, popped snacks based on mealworms and cassava. The mealworm composition varies from 10 to 20 percent in accordance with the product line (“classic” to “extreme”). According to focus groups, the taste is very pleasing and differs from other snacks, while the texture is as crunchy as other snacks. The prototype was made without preservatives or taste enhancers, and the high fat composition of mealworms removes the need for added fat. Crikizz won a prize in the national French contest Eco-trophélia 2012 for culinary innovation.

Silkworms

In most developing countries, animal production is hindered by scarcity and the expense of fishmeal as a feed ingredient. Although sericulture produces vast amounts of pupae, research dealing with silkworm caterpillar meal as a feed ingredient is scanty. In Nigeria, Ijaiya and Eko (2009) analysed the possibility of substituting fishmeal (by 25, 50, 75 and 100 percent) with silkworm (*Anaphe panda*) caterpillar meal in relation to the growth, carcass haematology and economics of broiler chicken production and found that the growth performance of chickens was not affected by the incorporation of silkworm caterpillar meal. There were no significant differences in performance in terms of feed intake, body weight gain, feed conversion efficiency or protein efficiency ratio between dietary treatments. Silkworm caterpillar meal proved less expensive than conventional fishmeal, making it well suited in economic terms as a substitute.

Mealworms

Mealworms (such as *Tenebriomolitor*) are already raised on an industrial scale. They can be grown on low-nutritive waste products and fed to broiler chickens. Ramos Elorduy*et al.* (2002) reared *T. molitor* larvae on several dried waste materials of different origins. They used three levels of larvae (0, 5 and 10 percent dry weight) in a 19 percent protein content sorghum–soybean meal basal diet to evaluate feed intake, weight gain and feed efficiency. After 15 days there were no significant differences between treatments. Mealworms are promising alternatives to conventional protein sources, particularly soybean meal.

Grasshoppers in India

In India, research has been conducted on the use of grasshoppers as feed for farm animals.

This is because conventional feed accounts for 60 percent of the total cost of raising farm animals, and also because there is a shortage of feedstuffs such as maize and soybean as a result of competition between humans and livestock for these resources. In addition, harvesting these food acridids in cropland and grasslands may allow a reduction in the use of harmful pesticides for their control. Four species of acridids were studied for their nutritional content: *Oxyafuscovittata*, *Acridaexaltata*, *Hieroglyphusbanian*and *Spathosternumprasiniferumprasiniferum*(Anand,Ganguly and Haldar, 2008). The study found acridids to have a higher protein content compared with the conventional soybean and fishmeal available locally.

Rearing and mass production

The use of acridids as animal feed requires a huge biomass, which can only be obtained by mass rearing in insect farms. Das, Ganguly and Haldar (2009) studied the space required for mass rearing *Oxyafus covittata*and *Spathosternum prasiniferumprasiniferum*. The use of jars with a volume of 2 500 cm3 and a density of 10 000 insects per m3 for *O. fuscovittata* and 7 100 insects per m3 for *S. pr. Prasiniferum* resulted in mortality rates of 12 percent and 15 percent, respectively. The smaller size of *S. pr. Prasiniferum* meant that more could be kept per unit area compared with *O. fuscovittata*. Das, Ganguly and Haldar (2010) also determined the optimum temperature and photoperiod to mass-rear *Oxyahylahyla* and experimented with the use of grasshopper manure for soil fertility enhancement. They found that the percentages of nitrogen, phosphorous and potassium were similar for acridid species compared with those for commonly used animal manure.

Processed mealworms for pet food, animal feed and human food

Hao Cheng Mealworm Inc. in China specializes in the farming and sale of mealworms, superworms and maggots. The farm, established in 2002, consists of 15 rearing facilities and produces 50 tonnes of living mealworms and superworms per month. Hao Cheng exports 200 tonnes of dried mealworms to Australia, Europe, North America and Southeast Asia each year.

The mealworms, superworms and maggots are sold live, dried, canned and in powder form. They have elevated protein content and can be used as additives for food as well
as feed:

- Food. Mealworm powder can be worked into bread, flour, instant noodles, pastries, biscuits, candy and condiments. The insects can also be consumed whole as meals and side dishes, or processed into medicinal supplements to fortify the human body's immune system.
- Feed. Entire insects can be used as direct feeds and feed supplements for pets such as birds, dogs, cats, frogs, turtles, shrimps, scorpions, chilopods, ants, goldfish and wild animals (Hao Cheng Mealworm Inc., 2012).

Processing techniques for transforming insects into insect meal

After being wild-harvested or reared in a domesticated setting, insects are killed by freeze-drying, sun-drying or boiling. They can be processed and consumed in three ways: as whole insects; in ground or paste form; and as an extract of protein, fat or chitin for fortifying food and feed products. Insects are also fried live and consumed. In countries where edible insects are traditionally eaten, food habits have shifted towards Western diets. To counter this, initiatives have been undertaken, for example, in Mexico, where tortillas are being enriched with yellow mealworm (Aguilar-Miranda *et al.*, 2002). This section gives examples of innovative projects that have developed promising edible insect products.

Whole insects

In tropical countries, insects are often consumed whole, but some insects, such as grasshoppers and locusts, require the removal of body parts (e.g. wings and legs). Depending on the dish, fresh insects can be further processed by roasting, frying or boiling. In the Lao People's Democratic Republic, among other countries, insects can be found in markets as ready-to-eat snacks or fried with lime leaves.

Granular or paste form

Grinding or milling is a common method for processing a large variety of foods. Soybeans, for example, are often transformed into tofu or other meat analogues. Meat is processed into products such as hamburgers and hot dogs, and fish into popular foods such as fish fingers. In much the same way, edible insects can also be processed into more palatable forms. They are often ground into paste or powder and added to otherwise low-protein foods to increase their nutritional value. An easy way to obtain powder is by dryingand grinding the insects. In Thailand and the Lao People's Democratic Republic, chilli paste with crushed and ground giant water bugs (*Lethocerusindicus*) is very popular as a main ingredient (and is known locally as jaewmaeng da in the Lao People's Democratic Republic and namphik in Thailand). The flavour of giant water bug is now reproduced artificially and is readily available. In societies where consumers are not accustomed to eating whole insects, granular or paste forms may be better accepted.

Extracted insect proteins

Western consumers may be reluctant to accept insects as a legitimate protein source because insects have never played a substantial role in their food culture. Extracting insect proteins for human food products – a process already being carried out – could be a useful way of increasing acceptability among wary consumers. In some cases, isolating and extracting insect protein is desirable to increase the protein content of a food product (Klaus and Yukiko, 2021). However, supplementing food products with insects in such a way requires extensive knowledge of the properties of the extracted proteins. These properties include, among others, amino acid profile, thermal stability, solubility, gelling, foaming and emulsifying capacity. Separating extracted protein groups based on their solubility in solvents produces water-soluble and water-insoluble fractions, which can be used for specific applications in both the food and feed industries. Alternative methods are enzymatic processes to obtain proteins of specific chain lengths. Alternative methods for protein separation are fluidized bed chromatography and ultra filtration.

At present, the cost of protein extraction is prohibitive. More research is required to further develop the process and to render it profitable and applicable for industry use. Wageningen University is conducting a programme on the sustainable production of insect proteins for human consumption (in the period 2010–2013) to further explore the possibility of extracting proteins from insects to fortify human foods. Under the project, dubbed Supro2, edible insects are reared on organic side streams, after which their proteins are separated, purified and characterized in order to tailor them for specific food products. Extracted insect proteins could also be considered in feed products, although the economic feasibility would need to be established (Catriona, 2015).

Termites: processing techniques in East and West Africa

- Winged termites are often fried in their own fat. Fried termites contain 32–38 percent protein (Cletus, 2021).
- In Uganda, termites are steamed in banana leaves (Arnold, 2017).
- Termites are boiled or roasted after swarming and then sun-dried or smoke-dried, orboth, depending on the weather.

- Sometimes termites are crushed with a pestle and mortar and eaten with honey. The fat residues of fried termites can be used to cook meat, a time-honoured practice among Azande and pygmies in the Democratic Republic of the Congo.
- Pygmies put the oil derived from frying or pressing dried termites into tubes and use itto treat their body and hair.
- In many East African towns and villages, sun-dried termites can be bought at local markets when in season.
- In Botswana, San women harvest winged termites (*Hodotermesmossambicus*), roastingthem in hot ash and sand.

Recent Efforts in Feeding Livestocks with Insects

There are several reports (Riddick, 2014; FAO, 2013) which proposed to use insects as protein sources for various animal species, mainly for fish. The most promising species for feed production are larvae of black soldier flies (H. illucens), common housefly larvae (M. domestica), silkworms (Anaphe panda), yellow mealworms, grasshoppers (Acridids spec.) and termites (K. flavicollis). These and other insects were successfully fed to rainbow trout (Danieli et al., 2011), red sea bream (Pagrus major) (Iwai et al., 2015) and catfish (Pimentel et al., 2004) and replacing a proportion of fishmeal and fish oil in the feed. Sealey et al. (2011) replaced 25 and 50 % of dietary fishmeal with two sources of black soldier fly prepupae (H. illucens) in feed of rainbow trout and found a lower weight gain in some cases, but no influence on sensory parameters. Lock et al. (2015) replaced up to 100 % of the fish meal with two different insect meals in feed for Atlantic Salmon (Salmosalar) for 15 weeks, and found that fish fed one insect meal performed as well as the fish raised on a fishmeal-based diet, whereas fish fed the other insect meal did not. Makkar et al. (2014) analysed in their review studies with catfish, tilapia, rainbow trout, Atlantic salmon, turbot and crustaceans, where fishmeal was replaced by dried black soldier fly larvae meal, housefly maggots, dried mealworms, locust meal, grasshoppers or silkworm pupae meal. Most studies demonstrated that about 50 % replacement of fishmeal had no adverse effect on animal performances.

The Edible Insects Projects by OPERA Research Center (2013) The necessity to guarantee food security to an always growing global population, that by 2050 is estimated to be greater than 9 Billion people, has driven with increasing interest to insect use as a protein source for humans1 and animal feed.The Edible Insects project wants to assert that consumption and breeding of edible insects represents one of the necessary ways to secure an increase in global food production in a sustainable way. The complexity and ever-growing quantity of scientific informations offers us a great indication of the importance of this theme in recent fields of study. Another relevant aspect that can be deduced is that there is a scarce level of in-depth analysis on the subject by the Italian political class. The importance of this theme has been underestimated by putting it in second place, with the evident risk of losing the opportunity to promote specific scientific R&D - despite important national projects are already in place – and moreover, losing the opportunity of being leaders at an international level of a project – slow but unstoppable – already in place as part of a shared sustainability program. Thematic areas have been identified and a trial was launched in which groups of experts from different public entities (universities and R&D centres across Italy) and private organisations committed to analyse current research and system state of the art, flaws and opportunities with the aim to propose effective research guides lines.

The potential of insects, both for feed and food, has been widely acknowledged recently, for example in the 2013 ‘Edible insects’ report published by the Food and Agriculture Organizational the United Nations. The report recognized at the same time that, despite the large potential of insects, “insect rearing for food and feed remains a sector in its infancy, and key future challenges will likely emerge as the field evolves” (van Huis et al., 2013).

Wageningen UR Livestock Research (2012) conducted a feasibility study to explore application of insects as a sustainable high protein feed ingredient for pig and poultry diets was conducted on request of the Dutch Ministry of Economic Affairs, Agriculture and Innovation. This feasibility study comprised a desk study and a workshop with participants representing the various links in the “insect chain”. The objective of the study was to list, in a joint initiative of industrial stakeholders and scientists, how insects can be used on a large scale as an alternative protein source in feed for pigs and poultry. The use of insects as a sustainable protein rich feed ingredient in pig and poultry diets is technically feasible. Insects can be reared on low-grade bio-waste and can turn this bio-waste into high quality proteins. Insects therefore can be an interesting link in the animal feed chain to fulfil the globally increasing demand for protein. Results from the workshop indicate that it is feasible to use insects on a large-scale as future feed ingredient. However, opinions differed on whether it would be possible to do it within five years or more. It was generally expected that the use of insects as a feed ingredient in aquaculture is the nearest future application, as well as the use in pet foods. The application of insects in poultry and pig feeding was also considered realistic. Main bottlenecks were identified in the area of legislation and the achievement of a low cost price by an automation of the production process. To introduce insects as a feed ingredient in the pig and poultry feed chain, additional research is recommended on its feeding value, inclusion levels in poultry and pig diets, functional properties of the feed ingredient, safety when using bio-waste as a rearing substrate, extraction of nutrients, shelf-life, and use of left-over substrates and residue products of insects.

Elaine Fitches from PROteINSECTS and Antoine Hubert from IPIFF (International Platform of Insects for Food and Feed) presented the qualitative and economic aspects of insect farming. Insects have high levels of highly digestible protein (up to 60%) and can harvest up to 150 tonnes per hectare in a very short life cycle. To become a sustainable protein supplier to the feed industry though, the experts differed on the ideal feed substrate. IPIFF members prefer to stick to vegetable substrates, meeting current EU legal requirements, with possible extension to former foodstuffs of animal origin like meat in the future. The EU-funded FP7 project PROteINSECTS pleas for exploration of other substrates such as manure and catering waste, which are not permitted in any type of EU livestock farming (including insect farming) for the time being. Tilemachos Goumperis from EFSA highlighted that generally speaking insects are safe for feed and food use, based on available data, but noted the need for more research in the area of microbiological risks and chemical contamination (Elaine, 2018).

As regards proteins of marine origin, Enrico Bachis from IFFO, the Marine Ingredients Organisation, made clear that fish meal resources are declining and fish by-products from fisheries (trimmings) and aquaculture are the key alternatives for the time being. Meal made from fisheries by-products has a very good amino acid profile; however, compared to wild-caught fish meal, it holds lower levels of protein content and higher levels of ash. Furthermore, for aquaculture by-products stricter regulation applies (intra-species recycling ban) and there is an increased risk of chemical and antibiotic residues. As far as algae are concerned, autotrophic production in large water tanks would likely be the most viable production method to deliver feed proteins in the future. Despite the fact freely available sunlight and CO_2 are used, meaning no competition for raw materials, the cost of production still has to come down to move from food to feed as an outlet. Bachis further highlighted the valuable protein source provided in the form of krill; however, this source is physically limited and may increasingly come into competition with direct food use. The growing of carnivorous marine worms, which can be fed on fish waste, has so far not proved to be financially viable and appears to accumulate contaminants.

PROteINSECT project's key publication recommends review of insect protein legislation & funding to help address European protein deficit -PROteINSECT fish feeding trials demonstrated insect meal can replace up to 50% of feed without affecting animal performance -PROteINSECT pig feeding trials revealed improved gut health in piglets -PROteINSECT poultry feeding trials showed that chickens fed on insect-containing diets performed as well as those fed on commercial diets (Rohanie, 2014).

The Global Food Security (2015) Programme has produced a report examining the potential of insects as animal feed following a workshop in August 2015. The workshop aimed to identify knowledge gaps and scope the priorities for research around the use of insects as an alternative animal feed.

African partners in Mali and Ghana from the EC-funded PROteINSECT project have released a film demonstrating the potential of insect-based animal feed as a cost-effective, additional and novel protein source – and are keen to share their expertise with farmers across Africa as well as in Europe and worldwide. The PROteINSECT consortium focusses on house fly (*M. domestica*) and black soldier fly (*H. illucens*) for evaluation of their potential as protein source in animal nutrition. However, the incorporation of insect proteins for the production of animal feeds depends upon bringing proteinoceous material into solution (Rohanie, 2014).

On Monday 13 April, 2016, the International Platform of Insects for Food and Feed (IPIFF) was officially launched. IPIFF draws together under a single voice insect-producing companies from the Netherlands, France, Germany and South Africa to support the development of the insect industry in Europe and worldwide. Elaine Fitches Co-ordinator of PROteINSECT welcomes 'the international collaborative industry platform approach being taken by IPIFF's president Antoine Hubert to facilitate discussions on the use of insects as food and feed'.

PROteINSECT's work in engaging with the public and tracking the impact of that work earned the EC funded project the runner-up spot in CommNet's Impact Awards (www.commnet.eu). PROteINSECT's entry covered the project's consumer survey which demonstrated greater support for the use of insects in feed than was expected, traditional media engagement via press releases, and the project's active social media campaign particularly on Twitter. Elaine Fitches, Co-ordinator, who presented PROteINSECT's work at the recent Impact Awards ceremony, said: "Having seen the high standard of work and presentations by other projects at the ceremony, I am delighted that PROteINSECT was short-listed and awarded the runner-up slot in the *Engaging Citizens* category. This is an important area of work for our project as consumer acceptance of the use of insects for animal feed is vital to the emergence of this innovative source of animal nutrition."

PROteINSECT participants from China, Africa, Belgium, Spain, England and Scotland met for a two-day project meeting (12/13 May) hosted by project partner Nutrition Sciences. As well as providing a timely update on scientific progress on production and processing of fly larvae, partners discussed plans for the imminent safety and quality testing, the newly announced engineering competition and the forthcoming industry and consumer surveys. Also high on the agenda was final arrangements for PROteINSECT's presentations and presence at the *Insects to Feed the World Conference* at Ede, The Netherlands (14-17 May) (PROteINSECT, 2014).

PROteINSECT participated in force at there cent Conference in Ede, The Netherlands, with presentations on media coverage, consumer surveys, current European legislation, safety & quality testing, life cycle analysis, and production systems in China and Africa. The project provided an information stand, presenting videos, stills photos and the opportunity for visitors from across the Insect food and feed sectors to speak with PROteINSECT experts (PROteINSECT, 2014). Over 100 delegates signed up to receive more project information, with some expressing particular interest in the soon to be announced Student Engineering Competition. Below are links to the slide sets of the presentations given on consumer acceptance by Rhonda Smith and current European legislation by Rosie Pryor.

Challenges limiting the use of insects as feed ingredients

Challenges facing the introduction of insects in animal feed relate to the development and application of appropriate technologies in handling, processing and storage of insects subsequent to harvesting. Technologies for animal feed production and feeding systems might require adaptations to this new ingredient without loss of efficiency and product quality, while providing the same guarantees in terms of hazard identification, risk assessment and traceability. In case of large-scale adoption of insects as feed ingredient, insect-rearing facilities need up-scaling into economically viable businesses. However, these technological challenges may fade against the challenges related to the legislative environment and marketplace acceptance (Arnold van Huis et al., 2013).

The use of insects in animal feed within the EU was prohibited following the EU transmissible spongiform encephalopathy (TSE) regulation EC 999/2001 and consecutive EU regulations on processed animal protein (PAP), which led to insects being categorized as ingredients that cannot enter the food chain (Veldkampet al., 2014). However, regulation EC 56/2013 has opened the debate by indicating that a lifting of the ban on the use of PAP from non-ruminants in non-ruminant feed could be considered under strict conditions. Consequently, the use of PAP from non-ruminant animals, including insects, was re-authorised for feeding aquaculture animals as of June 2013. It has been expected that an extension to pig and poultry feed might be considered at the earliest by 2015 (Smith and Pryor, 2013).

Similarly, the costs for production are currently too high. There may be an increased risk of accumulation of dioxin in the production cycle (waste-to-feed/food). There is a risk of Campylobacter contamination in insects as feed ingredients. This depends on the species and life stage of the insect and requires adequate processing of the insects (combining safe-sourcing with safe-processing). Product safety is vital and should be monitored. Environmental legislation may be an obstacle for large-scale production of insects. Novel diseases may arise when insects are produced on large-scale e.g. using waste (Remigiusz *et al.,* 2023)

Van der Spiegel et al. (2013) discuss food safety issues and legislative issues relating to edible insects in the EU. Concerning insects as food, it has not been decided yet in the EU whether an insect product is considered a novel food (definition: not consumed "in a significant degree" in the EU before May 15, 1997). If so, the producer has to provide a Novel Food Dossier, among others, proving the product is safe for the consumer.

Concerning insects as feed the EU issued a regulation in 2013 allowing the use of non-ruminant proteins in feed for fish in aquaculture; a lifting of the ban on insect proteins in the feed of food-producing pigs and poultry is being considered (Van der Spiegel, 2013), and a decision is expected in 2015.

Concerning allergies, people allergic to house dust mites and crustaceans may react to food containing insects, such as the Yellow mealworm *Tenebriomolitor* (Coleoptea: Tenebrionidae) Verhoeckx KCM, van Broekhoven S, denHartog-Jager CF, Gaspari M, de Jong GAH, Wichers HJ, et al. (2014). Recent evidence suggests that insects and crustaceans (like shrimps), long considered widely separated branches of the arthropod family tree, actually are taxonomically closely related (Pennissi, 2015) When proven allergenic, proper labelling of the insect product would be required.

Consumer acceptance is another issue. In tropical countries insects are used as an important protein source, while westerners are reluctant to use insects as food. Almost a hundred years ago, Arnold (2015) attributed the aversion of western people to include insects in their diet to 'prejudice', and cultural conditioning: "What we eat and what we do not eat is, after all, a matter of custom and fashion (rather) than anything else". Donkersley *et al*. (2022) also considered the western attitude and bias against eating insects a severe handicap to introducing this sustainable food source. Yen (2009)warned that 'westernization' of societies where insects are eaten would cause a movement away from entomophagy while western societies, being major consumers of livestock protein, would miss an opportunity to reduce their environmental footprint.

Insects contain a plethora of viruses and many of these are pathogenic to insects, i.e. they cause disease and may lead to mortality and colony collapse (Eilenberg et al., 2015; King et al., 2012). Most viruses in insects are specific at the family or species level and are therefore only pathogenic for invertebrates and not for humans or other vertebrates such as farm animals and birds. However, these insect-specific viruses are a major concern to producers farming insects for food and feed since they can cause loss in production (Eilenberg et al., 2015). All of these insect-specific viruses used for insect biocontrol are considered safe for vertebrates including humans and include those that are intentionally added to food or feed crops (Gröner, 1986; Laird et al., 1990); Leuschner et al., 2010; Sundh et al., 2012).

There is currently a lack of consolidated information relating to the magnitude and frequency of feeding of insects to farm animals. Whilst the feeding of farmed insects to livestock in Europe is currently restricted by legislation which make it economically and legally challenging to do so, information provided by relevant stakeholders that were invited to provide information as hearing experts at a working group meeting and through on-going research indicates that fly larvae and mealworms are being fed particularly to chickens and fish in Africa, China and other parts of Asia such as Thailand. According to the nutritional composition and feeding studies, insects can be a component of the feed in the same way as other protein sources such as fish meal or soya. Insects would not replace 100 % of traditional feed ingredients, but make up a proportion of the feed (Arnold van Huis *et al.* 2013).

Strategies for commercial production of insects as feed ingredients

Innovation in mass-rearing systems is taking place in many countries. China already produces insects for use in aquaculture. In Western Europe, insects are reared for pets and zoo animals as well as for fishing bait (Singh, 2022). In developing countries, small-scale businesses already produce insects to be sold as poultry feed. A company in the United States is using DDGS as a food source for BSF and is already selling its high-protein larval meal for use in aquaculture.

Large-scale insect production is not just blue-sky thinking, but the subject of discussion for the Food and Agriculture Organization (FAO) and research institutes internationally. PROteINSECT for example, aims to create a pro-insect platform to share experience and expertise in rearing, processing and using insects as a component of animal feed. With partners in Europe, Asia and Africa, the group is focused on optimizing rearing systems for insects; ensuring the quality and safety of insect meal; and demonstrating its efficacy in monogastric nutrition (Zoe Kay, 2014). Life-cycle analysis will also be a focus as a way of assessing the environmental impact of insect protein production processes.

CONCLUSION

Possible functional properties of insects (i.e. chitin) may facilitate the use of insects as feed ingredients. A low carbon footprint would facilitate insects such as mealworms to be used as feed ingredients. The use of insects in pet foods may be profitable as the value of pet food is higher than that of pig/poultry feed. Insects are already being used in feed for fish, birds and hamsters. On the other hand, relatively cheap animal co-product meals are used in pet foods making it less feasible to incorporate insects in pet foods. It may therefore be more feasible to apply insects as feed ingredients in aquaculture or in pig and poultry diets.

In lieu of the above and based on the potentials of using insects as livestocks feeds, it can be concluded that the overall positive atmosphere surrounding the idea of using insects in animal feed, as it emerges from this discussion, indicates the momentum is right to move forward with the policy debate and take advantage of this novel source of protein for use in animal feed.

RECOMMENDATIONS

Based on the above, the following are recommended.

Mass-production technologies:

- Increase innovation in mechanization, automation, processing and logistics to reduce production costs to a level comparable with other feed and food sources.
- Develop feeding tables for insects and the nutritional value of substrates.
- Conduct more extensive life cycle assessments among a vast array of insect species to enable comparisons of insects with conventional feed and food sources.
- Maintain resilient genetic diversity to avoid colony collapse in insect farming systems.

Food and feed safety:

- Investigate the potential of insect allergies in humans and the digestibility of chitin (a principal constituent of the exoskeleton of insects).
- Expand data on the nutritional value of edible insect species and their contributions to animal and human health.
- Research the risk of potential zoonosis, pathogens, toxins and heavy metals (through the use of bio-waste streams) from entomophagy.
- Develop means of increasing shelf life.

Legislation:

- Develop voluntary codes and regulatory frame works governing insects as food and feed, as well as human health and animal welfare at the national and international levels(e.g. the Codex Alimentarius) .
- Improve risk assessment methodologies for risks related to mass-rearing and wild gathering in order to safeguard against the introduction of alien and invasive insect species to wild populations.

Consumer acceptance and education:

- Support entomophagy in cultures where it is already prevalent.
- Conduct comprehensive research into the ecology of species promoted for consumption or farmed.
- Educate consumers on the benefits of entomophagy.
- Develop new ways of integrating insects into the diets of abroad range of consumers through the creation of insect based products.
- Promote insects as a supplement to feed.

Clarify what the legal status is of insects as feed ingredients (cat III; invertebrates that are non-pathogenic; processed animal protein). Compilation of feeding tables for insects is required. In such tables, the nutritional value of substrates for specific insects should be described. The focus should be on the use of (low quality) substrates for growing insects and not on the use of substrates that are currently already directly used as feed ingredient for livestock. Then, novel substrates should be evaluated.

Research is required for housing insects' nutritional value of substrates for insects determining the nutritional value of insects' safety assurance. The research can be performed in a collaborative approach by independent research institutes and feed companies; and results can be made publically available.
Various players in the production chain should be involved in research, and strong coordination of research is important. Development of an insect rearing model by companies and researchers can provide a proof of- concept and facilitate the production and use of insects as feed ingredients on a large scale.
Use expertise on processing technologies in the fish& shrimp and animal co-product industries for processing of insects to feed ingredients.
Up scaling of insect production will lead to profitability. Lowering of production costs can be achieved by an increase in mechanisation and technology. Identify critical factors that contribute to the success of prototypes.
Involve NGOs to support the use of insect proteins or insects as feed ingredients.
For large-scale production of insects: Closed systems are required. Different life stages/breeding stocks are kept separately. Monoculture should be used. Storage between substrates for insects should be separated. Specific procedures for stress-free killing are required. Specific methods of storage of products.

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