7. Insects as animal feed

7.1 OVERVIEW

In 2011, combined world feed production was estimated at 870 million tonnes, with revenue from global commercial feed manufacturing generating approximately US$350 billion globally. FAO estimates that production will have to increase by 70 percent to be able to feed the world in 2050, with meat outputs (poultry, pork and beef) expected to double (IFIF, 2012). Despite this, little has been said about the opportunities insects offer as feed sources (Box 7.1). At present, ingredients for both animal and fish feed include fishmeal, fish oil, soybeans and several other grains.

A major constraint to further development are the prohibitive costs of feed, including meat meal, fishmeal and soybean meal, which represent 60–70 percent of production costs. Another problem is manure disposal, which is becoming a serious environmental problem; it is not uncommon for large amounts of manure to be stockpiled in open-air lots, swarming with flies.

BOX 7.1

International Feed Industry Federation and FAO: looking for new, safe proteins

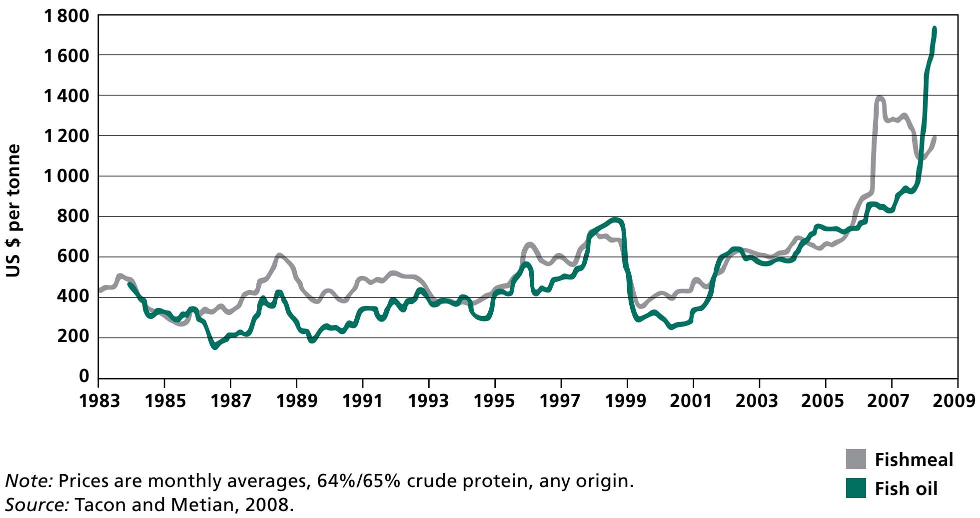
The International Feed Industry Federation (IFIF) is a global organization mandated to play a coordinating role in promoting the sustainable supply of safe, healthy feed in the global feed industry. Its function is fundamentally important in developing countries, especially where national feed associations and sectors are weak or non-existent. In the late 1990s, the IFIF received Codex Alimentarius non-governmental organization (NGO) status, which was a first step towards improving the ways in which government regulates the industry. During this time, the IFIF began developing a close working relationship with FAO. Participation in Codex and FAO meetings has enabled the IFIF to follow up on the development and harmonization of international codes, standards and practices that affect feed manufacturers worldwide. Specifically, the IFIF has developed the *Codex Code of Practice of Good Animal Feeding*; participated in the Codex electronic working group on animal feeding; supported an FAO Expert Consultation on Protein Sources for the Animal Feed Industry; and developed the joint biannual Global Feed and Food Congress. Additionally, together with FAO, the IFIF has developed a *Manual of Good Practices for the Feed Industry* and established a meeting point for feed associations and feed regulators at an annual International Feed Regulators Meeting. The IFIF is convinced that sound scientific and technological advances will make a difference in ensuring that food is safe, plentiful and affordable to all.

Fishmeal prices are on the rise (Figure 7.1). Increased demand in 2010 and 2011 led to sharply higher prices and, although demand softened in late 2011 and early 2012, prices remain high. For small farmers, this means that fishmeal is less accessible. At the same time, aquaculture is the fastest-growing animal-food producing sector and will need to expand sustainably to keep up with increasing demand for fish.

At present, around 10 percent of global fish production goes to fishmeal (i.e. either whole fish or fish remains resulting from processing) and is used mainly in aquaculture (FAO, 2012b). South America is the biggest producer of fishmeal, through its catch of anchoveta. Anchoveta catch is highly variable because it is dependent on the El Niño climatic cycle. Production (catch) peaked at 12.5 million tonnes in 1994 but declined to 4.2 million tonnes in 2010 and is expected to fall further.

Insects have a similar market to fishmeal; they are employed as feed in aquaculture and livestock and also used in the pet industry. Recent high demand and consequent high prices for fishmeal, together with increasing production pressure on aquaculture, has led to research into the development of insect proteins for aquaculture and livestock (which could eventually supplement fishmeal). Meanwhile, aquaculture is growing and fishmeal is declining rapidly as a source of feed (Box 7.2) because of decreased supplies of industrially caught fish due to tighter quotas, additional controls on unregulated fishing, and greater use of more cost-effective dietary fishmeal substitutes (FAO, 2012b). The search for alternative and *sustainable* proteins is an issue of major importance that needs viable solutions in the short term, making insects an increasingly attractive feed option.

FIGURE 7.1
International wholesale market price for fish oil and fishmeal, CIF Hamburg



Note: Prices are monthly averages, 64%/65% crude protein, any origin.
Source: Tacon and Metian, 2008.

BOX 7.2
Fish for non-food uses

The amount of captured fish for non-food uses increased between 1976 and 1994. Since then it has declined, however, from 34 percent of the total catch in 1995 to about 26 percent in 2009, and as a consequence the total amount destined for fishmeal and fish oil has also declined (from about 30 percent to 20 percent). In 2008, aquaculture used 61 percent of world fishmeal production and 74 percent of fish-oil production. However, fishmeal use in aquafeeds has fallen from 19 percent in 2005 to 13 percent in 2008, and it has been predicted that it will decrease to 5 percent by 2020.

7.2 POULTRY AND FISH FED WITH INSECTS

Insects are natural food sources for many fish and poultry. Chickens, for example, can be found picking worms and larvae from the topsoil and litter where they walk. There is a reason, too, why maggots are used as fish bait in recreational fishing. Given insects' natural role as food for a number of farmed livestock species, it is worth reconsidering their role as feed for specific poultry and fish species (Box 7.3).

BOX 7.3
Which insects are currently used in animal feed?

FAO's Animal Feed Resources Information System (now called Feedipedia) provides information about the use of insects as animal and fish feed, including insects such as the desert locust (*Schistocerca gregaria*), common housefly maggots (*Musca domestica*) and domesticated silkworm (*Bombyx mori*). Information on source, processing, feeding guidelines, feeding experiments, feeding guidelines and nutrients characteristics are available under the category "animal products".

However, many other insect species may also be well suited to industrial-scale feed production, such as Coleoptera, which are presently raised by ornamental collectors (see Chapter 2).

7.2.1 Poultry

The poultry industry has expanded rapidly in developing countries in the last two decades. Grasshoppers, crickets, cockroaches, termites, lice, stink bugs, cicadas, aphids, scale insects, psyllids, beetles, caterpillars, flies, fleas, bees, wasps and ants have all been used as complementary food sources for poultry (Ravindran and Blair, 1993). In developing countries, animal and plant proteins supply the amino acids (e.g. lysine, methionine and cystine) in poultry feed. Animal-based, protein-rich feed ingredients are generally made up of imported fish and meat or blood meal, while plant-based resources include imported oil cakes and leguminous grains. Termites have reportedly been used as feed for chickens and guinea fowl in Togo and Burkina Faso (see section 2.3) (Iroko, 1982; Farina, Demey and Hardouin, 1991).

Chitin, a polysaccharide found in the exoskeleton of insects, may have a positive effect on the functioning of the immune system (see section 10.3). By feeding insects to chickens, the use of antibiotics in the poultry industry – which may lead to human infection with drug-resistant bacterial strains (Box 7.4) – may be diminished.

BOX 7.4
Chicken consumption leading to human infection with highly drug-resistant ESBL strains

In the Netherlands, patients suffering from serious urinary tract or bloodstream infections were evaluated. One in five of these patients were infected with ESBL (extended spectrum beta-lactamase) bacteria genetically identical to bacteria found in chicken. ESBL-containing strains of bacteria produce enzymes that bring about resistance to antibiotics like penicillin and the cephalosporins. Two bacteria – *Escherichia coli* and *Klebsiella pneumoniae* – most commonly produce ESBL enzymes. About 35 percent of the human isolates contained poultry-associated ESBL genes. The use of antibiotics is higher in the Dutch poultry industry than in any other European country; consequently, ESBL prevalence is correspondingly high. The study also revealed that nearly all (94 percent) chicken in Dutch supermarkets and at poultry farms are infected with ESBL bacteria, possibly due to the common use of antibiotics in their feed. Research is needed to ascertain whether feeding chickens with insects (containing chitin) will make the use of antibiotics superfluous by strengthening the immune system.

Source: van Hall *et al.*, 2011.

Ravindran and Blair (1993) cited the use of soldier flies (*Hermetia illucens*) grown on manure and housefly pupae (*Musca domestica*) as replacements for soya meal in poultry diets. Likewise, studies have shown how silkworm pupae – byproducts of silk manufacturing – can replace fishmeal entirely in the diets of layer chickens (i.e. in egg production) and supplement chicken diets (50 percent). Grasshoppers and Mormon crickets (*Anabrus simplex*) can also replace fishmeal and soy meal entirely.

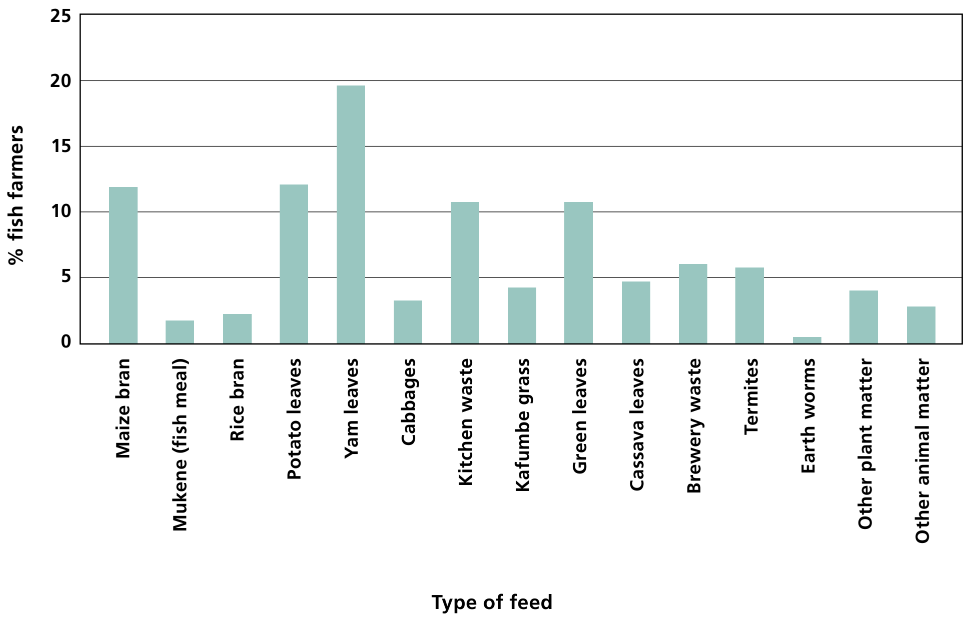
In South Kivu, the Democratic Republic of the Congo, Munyuli Bin Mushambanyi and Balezi (2002) explored the possibility of replacing extremely expensive meat meal – a 20 percent feed ingredient in poultry farming – with flour derived from cockroaches (*Blatta orientalis*) and termites (*Kalotermes flavicollis*). Their study showed that the insect-derived flour could replace the meat meal ingredient when incorporated in the feed.Ramos Elorduy *et al.* (2002) conducted similar experiments with mealworms (*Tenebrio molitor*), rearing them on low-nutritive waste products and feeding them to broiler chickens. The mealworms were able to transform the low-nutritive waste products into a high-protein diet, making *T. molitor* a promising source of alternative protein, in particular as a replacement of soybean meal in poultry feed. Similar results were found in trials with *Anabrus simplex*, *Acheta domesticus*, *Bombyx mori*, *Alphitobius diaperinus*, *Tribolium castaneum* and termites (Ramos Elorduy *et al.*, 2002).

In India, the poultry industry is one of the fastest-growing agro-businesses, but the use of expensive maize as a feed ingredient is threatening the survival of farmers. Feeding poultry with sericulture waste, which until now has only been used for biogas production and composting, showed better conversion rates than those obtained through the use of conventional feed stock (Krishnan *et al.*, 2011).

7.2.2 Fish

Insects as sources of fish feed remain underappreciated in most parts of the world. In Uganda, a vast array of ingredients are used as fish feed, including vegetables, grass,

FIGURE 7.2
The proportional use of different types of feed by Ugandan fish farmers



Source: Rutaisire, 2007.

cereals, cereal brans, oil seed cakes, industrial and kitchen wastes and fishmeal, as well as insects (Figure 7.2). The availability of most of these ingredients is seasonal (Rutaisire, 2007). Five percent of farmers use termites for feeding fish – either collecting the termites directly or purchasing them from collectors at a cost of US$0.27/kg – from March to April and from August to September. The quantity available depends largely on the number and size of termite hills on the farm, moonlight intensity and termite species. On average, a termite hill yields approximately 50 kg per year. In Southeast Asia it is very common to hang fluorescent lights above fish ponds. The light attracts the insects, which because of its reflection in the water, fall into the pond where they are eaten by fish. Wingless grasshoppers and crickets (which cannot float) are also used as fish bait, as are ant larvae and pupae (e.g. *Oecophylla smaragdina* in the Lao People's Democratic Republic) (J. Van Itterbeeck, personal communication, 2012).

7.3 KEY INSECT SPECIES USED AS FEED

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.

7.3.1 Black soldier flies

Black soldier flies (*Hermetia illucens*) (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 byproducts). 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 manure and chicken manure produce 36 g, 58 g and 91 g, respectively, of biodiesel (Li *et al.*, 2011). The possibility of recovering chitin after oil recovery is also being explored (see section 9.1).

Reducing populations of houseflies

Many environmental problems associated with manure storage and management can be solved by black soldier fly prepupae production. Sheppard *et al.* (1994) documented how the colonization of poultry and pig manure by black soldier flies can reduce populations of common housefly (*Musca domestica*) by 94–100 percent. Black soldier flies also make manure more liquid and thus less suitable for housefly larvae, and their presence is believed to inhibit oviposition by the housefly (Sheppard, 1983). While generally considered a nuisance, houseflies can also be reared as animal and fish feed.

Reducing manure contamination

Black soldier fly larvae are capable of converting residual manure proteins and other nutrients into more valuable biomass (e.g. animal feedstuff). In this way they reduce nutrient concentration and the bulk of manure residue. The harvested and processed black soldier fly larvae, valued at approximately US$200 per tonne, can also be more economically transported than manure (valued at US$10–20 per tonne) (Tomberlin and Sheppard, 2001). In confined bovine facilities, the larvae were found to reduce available phosporous by 61–70 percent and nitrogen by 30–50 percent (Sheppard, Newton and Burtle, 2008). In a field trial conducted in Georgia, United States, black soldier fly larval digestion of pig manure reduced nitrogen by 71 percent, phosphorous by 52 percent and potassium by 52 percent, and aluminium, boron, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, sodium, sulphur and zinc by 38–93 percent. Thus, the larvae are able to reduce pollution potential by 50–60 percent or more. Foul odours produced by decomposing manure were also reduced or eliminated by black soldier fly larval digestion. This is because the species aerates and dries the manure, reducing odours. Additionally, the larvae modify the microflora of manure, potentially reducing harmful bacteria (Erickson *et al.*, 2004; Liu *et al.*, 2008). For example, larval activity significantly reduced *Escherichia coli* 0157:H7 and *Salmonella enterica* in hen manure (Erickson *et al.*, 2004). Sheppard, Newton and Burtle (2008) suggested that the larvae contain natural antibiotics similar to the larvae of the common green bottle fly (*Lucilia sericata*) used in maggot debridement therapy for cleansing human wounds, a method increasingly practised because of the prevalence of drug-resistant bacterial infections (Sherman and Wyle, 1996).

Black soldier flies as animal feed

The use of black soldier fly prepupae as animal feed should be seriously considered, not least for their reduced environmental footprint (Newton *et al.*, 1977; Sheppard *et al.*, 1994) (Box 7.5). Dried black soldier fly prepupae contain 42 percent protein and 35 percent fat (on a dry matter basis) (Newton *et al.*, 1977). Live prepupae 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 (*Oncorhynchus mykiss*) (St-Hilaire *et al.*, 2007), channel catfish (*Ictalurus punctatus*) (Pimentel *et al.*, 2004) and blue tilapia (*Oreochromis aureus*) (Sheppard *et al.*, 2008). In the case of rainbow trout, the larvae can replace 25 percent of fishmeal 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).

BOX 7.5

Increasing the sustainability of freshwater prawn production in Ohio

Freshwater prawn culture is increasingly popular in many temperate regions in the United States. Freshwater prawns have great potential for the diversification of Ohio farms. In the past ten years, interest in this product has increased due to rising demand for locally raised products, the growing desire among consumers to know where and how their food is produced, the uniqueness of the product, and increases in production rates for prawns based on new management and production practices.

Feed is the second highest contributor to variable production costs (the first being larval prawn procurement). Traditionally, most prawn farmers use a sinking catfish feed. With costs of these fishmeal-based diets continuing to rise, many animal nutritionists are looking for alternative protein sources to use in aquaculture feeds. One of these is black soldier fly larvae and their frass, or castings. For the first time in the United States, black soldier fly larvae are being cultured on a commercial scale in Yellow Springs, Ohio, by a company called EnviroFlight, where the first prawn diets using black soldier fly frass and wheat middlings as ingredients were produced.

The only notable difference was that the prawns fed the Enviroflight diet were slightly paler in appearance than those fed the traditional diet. Experienced prawn taste-testers

Continues

Box 7.5 continued

detected no flavour difference between the two products. Using a locally produced aquaculture feed has many benefits for Ohio freshwater prawn producers, as well as potential benefits for aquaculture producers growing other fish species. First, the cost of the feed is lower than currently commercially available alternatives. This will contribute to the economic efficiency of operations, especially considering that the cost of fishmeal is predicted to continue to rise. Given that the feed is produced in Ohio, fewer "food transportation miles" can be attributed to its production and distribution. Additionally, feeding prawns a diet devoid of fishmeal may open additional marketing opportunities for farmers, as some customers are opposed to the use of fishmeal in aquaculture feeds. Finally, given that the black soldier fly larvae eat dried distiller's grains, the production of this product actually aids the efficient reuse of waste/coproducts derived from another Ohio industry. This recycling of nutrients adds to the overall sustainability of the project.

Source: Tiu, 2012.

7.3.2 Common housefly larvae

Maggots – the larvae of the common housefly (*Musca domestica*) – develop predominantly in 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 fishmeal 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 fishmeal in broiler-chick feeding.

The inclusion of maggot meal in livestock diets, however, raises concerns because common knowledge suggests that, in its adult form, *Musca domestica* is widely involved in the transmission of disease. The larvae develop in manure and decaying filth; for this reason, 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.

7.3.3 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).

7.3.4 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.

7.3.5 Mealworms

Mealworms (such as *Tenebrio molitor*) 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.

7.3.6 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: *Oxya fuscovittata*, *Acrida exaltata*, *Hieroglyphus banian* and *Spathosternum prasiniferum prasiniferum* (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 *Oxya fuscovittata* and *Spathosternum prasiniferum prasiniferum*. The use of jars with a volume of 2 500 cm^3 and a density of 10 000 insects per m^3 for *O. fuscovittata* and 7 100 insects per m^3 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

Oxya hyla hyla 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.

Feeding trials with fish and poultry

Feeding trials on certain fish species revealed that diets in which 25 percent and 50 percent of fishmeal was replaced with acridid meal produced results as good as the control diet comprising 100 percent fishmeal. All growth parameters measured for the selected fish were higher for the formulated feed containing acridid meal than for those fed with market-available diets. This indicates that acridids could prove a successful meal replacement for conventional fishmeal.

Japanese quail (*Cotornix japonica japonica*) were fed with various diets in which *Oxya* meal gradually replaced fishmeal. For a range of growth parameters, the best results were obtained with the diet in which 50 percent of fishmeal was replaced with *Oxya* meal. Moreover, fecundity (i.e. the number of eggs laid per female) was significantly higher compared with the control treatment.

Thus, among the selected acridids, two nutritionally rich species of the genus *Oxya* (*O. fuscovittata* and *O. hyla hyla*) have the ability to produce substantial biomass due to their elevated rates of fecundity and fertility. It is estimated that *Oxya* could replace at least 50 percent of fishmeal to feed fish and poultry birds. These results support the idea of establishing acridid farms in which *O. fuscovittata* and *O. hyla hyla* are mass-reared using *Sorghum halepense* grasses and *Brachiaria mutica* plants as food. The transition to acridid tissues would be relatively simple, ensuring the provision of a constant source of feed for developers to supplement the diets of livestock intended for human and non-human consumption. Moreover, if acridids are popularized as alternative food and feed sources, this could significantly lower the rate of overexploitation of fishmeal and consequently decrease the demand/supply ratio of fishmeal, helping to reduce market prices (Haldar, 2012).