Journal of Cleaner Production 65 (2014) 16–27

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Review

Insect meal as renewable source of food for animal feeding: a review

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A R T I C L E I N F O

Article history:
Received 5 October 2013
Received in revised form
18 November 2013
Accepted 25 November 2013
Available online 4 December 2013

Keywords:
Alternative feed
Rearing-mass
Nutritive composition
Protein
Fatty acids
Animal feeding

A B S T R A C T

The massive utilisation in animal feeding of soy or fishmeal poses severe environmental issues. The insects could be a sustainable protein source. This article documents 150 species of insects that are currently commercially available in the EPPO (European and Mediterranean Plant Protection Organization) region and in North America. Furthermore, the various data regarding body composition are analysed. Amino acids and fatty acids of several insect species are compared with the composition of soy and fishmeal as principal protein sources for animal feeding. As a protein source, insects, depending on the species, have an adequate profile of amino acids. The more frequent limiting amino acids are histidine, lysine, and tryptophan, which could be incorporated into the diet. In conclusion, insects appear to be a sustainable source of protein with an appealing quantity and quality and acceptable nutritive properties. In conclusion, the use of insects as a sustainable protein rich feed ingredient in diets is technically feasible, and opens new perspectives in animal feeding.

1. Introduction

Feed was identified as the major contributor to land occupation, primary production use, acidification, climate change, energy use and water dependence (Mungkung et al., 2013). The productions of fishmeal or soy meal are mainly linked to these impacts.

The nutritive needs of monogastric species, particularly fish, include a high quality and quantity of protein in the diet. From a nutritional point of view, protein sources must have a high-protein content, an adequate amino acid profile, high digestibility, good palatability and no anti-nutritional factors (Barrows et al., 2008). Fishmeal and soy meal are the two of the most useful protein sources in animal feeding.

Fishmeal is obtained from the fishery. The fish catch data refer to the total global landings in 2009; 22.8 million tons of fish caught were for non-food uses (25.7%). Of this volume, 17.9 million tons (20.2% of total) were transformed into fishmeal and oil meal (FAO, 2012). Currently, the world production of fishmeal and fish oil has stabilised at approximately 5.0–6.0 million tons per year. The soybean crop is one of the most widespread in the world and grew by 1.4% from 2010 to 2011. In 2009, soybean production reached 210.9 million tons, which is slightly more than 50% of the total production of oilseed meal (FAO, 2012).

Soy meal has a high digestibility, high quality and quantity of protein and the best amino acid profile of the vegetable protein sources available, together with other nutritive benefits. Vegetable feedstuffs have several unfavourable characteristics, such as imbalances between essential and nonessential amino acids, antinutritional factors, low palatability and a high proportion of fibre and non-starch polysaccharides, which limit the percentage of inclusion in the diet. Under these conditions, it becomes necessary to complete the diet by adding amino acids or a high value protein source, such as animal protein, which has high digestibility and a good balance between essential and nonessential amino acids (Refstie et al., 1997, 1998; Webster et al., 1992, 1995).

Fishmeal has the advantages of animal protein sources, together with excellent nutritive properties that are indispensable, particularly for fish. These advantages, together with the current laws forbidding the use of most meat meals due to problems of food security, make fishmeal the most used animal protein source.

However, the massive utilisation of soy or fishmeal poses severe environmental issues. On one hand, increased soy cultivation causes the deforestation of areas with a high biological value (Carvalho, 1999; Osava, 1999), high water consumption (Steinfeld et al., 2006), the utilisation of pesticides and fertilisers (Carvalho, 1999), and transgenic varieties (Garcia and Altieri, 2005), which cause significant environmental deterioration (Osava, 1999). On the other hand,

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0959-6526/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2013.11.068

Abbreviation list

A	adult
AAE	essential aminoacids
AANE	no essential aminoacids
ARA	arachidonic acid (20:4$n-6$)
CP	crude protein
DHA	docosahexaenoic acid (22:6 *n*3)
E	eggs
EE	ether extract
EPA	eicosapentaenoic acid (20:5 *n*3)
EPPO	European and Mediterranean Plant Protection Organization
FCR	feed conversion ratio
HUFA	highly unsaturated fatty acids
L	larvae
MUFA	mono unsaturated fatty acid
N	ninpha
NA	not available
ND	not detected
NFE	nitrogen-free extract
NPU	net protein utilisation
O	order
P	pupae
PER	protein efficiency ratio
PUFA	polyunsaturated fatty acids
SGR	specific growth rate

fishmeal is a resource that depends on the catch, therefore its production is quantitatively and qualitatively variable (FAO, Animal Feed Resources Information System). In addition, the deterioration of the marine environment and stripping of fisheries have resulted in a decrease in fishmeal production and an increase in the price from US$ 600/metric ton in 2005 to US$ 2000/metric ton in June 2010. This trend to increase prices is likely to continue (International Monetary Fund, 2010), with consequent economic repercussions on animal production. This situation reveals the importance of renewable sources of proteins, which are particularly important in the diet of fish, because fish require a high percentage of protein in their diet, either in fishmeal or through another protein source (Manzano-Agugliaro et al., 2012).

Currently, insects are being considered as a new protein source for animal feed (Premalatha et al., 2011). There are approximately one million known species of insects, although it has been estimated that their global diversity is as high as 80 million (Erwin, 2004). Grimaldi (Grimaldi and Engel, 2005) suggested that only approximately 20% of insects have been named and described. More than 58% of the known global biodiversity are insects (Foottit and Adler, 2009).

When using insects as a food source for animal feed there are several factors to consider, which include the natural feeding habits of many species, such as poultry, pig, and all cultivated species of fish, including invertebrates, such as oligochaeta, crustaceans and insects (Bell et al., 1994; Khan and Panikkar, 2009; Matsuno et al., 1999; Matthews, 1998). Insects have different feeding habits and can be fed by-products (slaughter house, restaurant surpluses, cereal remnants, etc.), whose elimination has an economic and environmental cost; insects can be reared under different conditions to optimise their nutritive value (Sealey et al., 2011). Some insect species can be grown on organic side streams, reducing environmental contamination and transforming waste into high-protein feed that can replace increasingly more expensive compound feed ingredients, such as fish meal. Then, from an environmental point of view, insect cultures are sustainable; culturing insects is usually performed in warehouses, with no need for large areas or much water, particularly when compared with crops. In addition, culturing insects contributes to the recycling of waste. On the other hand, insect by showed relative low scores on carbon footprint (Blonk et al., 2008). In addition, insects are efficient food converters because they do not use energy to maintain a high body temperature (Nijdam et al., 2012).

Due to the only recent interest in the use of insects as an alternative protein source, the nutritive properties are not well known. Previous studies on the nutritive composition of insects have focused on human nutrition, and most of those insects demonstrate a good composition for use as human food (Banjo et al., 2006; Ramos-Elorduy, 1997; Ramos-Elorduy et al., 1982). Recent studies even mention insect development as a source of protein for human consumption for space missions (Katayama et al., 2008). Nevertheless, the utilisation of insects in animal feeding has been less studied; insects exhibit great potential for development as a standard ingredient in animal feeding. This review analyses the potential use of insect meal in animal feeding, studying the nutritive values, currently cultured species and the published findings regarding their use in animal feeding.

2. Mass-rearing of insects

The utilisation of insect meals in animal feeding requires the mass production of insects, ensuring a significant production of insects that are necessary for animal food production. Although mass-rearing has been developed for some insect species, no other insect cultures have been developed, most likely because of a lack of demand. The culture of insects is complicated because insects have strict environmental (temperature and humidity), feeding and population requirements, particularly during reproduction (Leppla, 2002). The culture of insects can be partial (from egg to larva or nymph and adult) or complete (egg–egg). The easier insects to culture are the small, multivoltine herbivores that are terrestrial, with low environmental requirements, such as pest species of crops or stocked product or gardens (Leppla, 2002). In this manner, mass-rearing has been developed, particularly for silk production, fishing bait, and pet food (Schabel, 2010).

The integrated and biological control of crop pests has provoked an interest in the knowledge of insect biology and the development of culture systems. One example is industrial warehouses that produce *Bactrocera cucurbitae* in Okinawa, Japan, which produce 40 million larvae per week (Mitsuhashi, 2010).

Cultured species include butterflies and moths (O. Lepidoptera, more than 300 species have been raised), beetles (O. Coleoptera, more than 200 species), flies and mosquitoes (O. Diptera, approximately 200 species), bugs (O. Heteroptera, less than 100 species) and bees and wasps (O. Hymenoptera, less than 100 species). Crickets and grasshoppers (O. Orthoptera), lacewings (O. Neuroptera), cockroaches (O. Blattodea), termites (O. Isoptera) and fleas (O. Siphonaptera) are also bred (approximately 10–20 species) (Leppla, 2002).

An example of mass-rearing in Table 1 indicates insects that have been used for the biological control of arthropod pests, which are or have been commercially available in the EPPO zone (European and Mediterranean Plant Protection Organization) (EPPO, 2010) and North America (Hunter, 1997) used for the biological control of arthropod pests, which are or have been commercially available in the EPPO zone (European and Mediterranean Plant Protection Organization).