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Review

Review on the use of insects in the diet of farmed fish: Past and future

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ABSTRACT

The decrease in the availability and the increase in the prices of fishmeal and fish oil have prompted the search for sustainable alternatives for aquaculture feeds. Insects, which are part of the natural diet of fish, leave a small ecological footprint and have a limited need for arable land, may represent a good candidate. Over the last decade, studies of the replacement of fishmeal with insects in the diet of fish have emerged and the promising results have encouraged further research. The present review displays these results in tables and emphasizes the achievable dietary inclusion levels. It discusses the potential of locusts, grasshoppers, termites, yellow mealworms, Asiatic rhinoceros beetles, superworms, domesticated silkworms, common houseflies, common mosquitoes and black soldier flies for use as fishmeal and/or fish oil replacement in the fish diet. The review succinctly compares the composition of the insects with the requirements of the fish (proteins and amino acids, lipids and fatty acids, vitamins and minerals). This review also discusses the potential hurdles of using insects in fish feeds (toxicity of insects through bioaccumulation, deficiencies in amino acids or fatty acids, chitin content, palatability, digestibility), and the available ways of avoiding these drawbacks (control of the dietary substrate of insects in mass rearing units, manipulation of the diet of insects, mixture of dietary proteins, use of aquatic insects, processing of insect meal). Finally, it suggests paths worthy of future research on these new fishmeal alternatives.

Contents

Abbreviations: AA, amino acid; ADF, acid detergent fibre; BSF, black soldier fly; CP, crude protein; DM, dry matter; EAA, essential amino acid; FA, fatty acid; FM, fishmeal; FO, fish oil; HUFA, highly unsaturated fatty acid; Lys, lysine; Met, methionine; %FMr, percentage of fishmeal replacement; PUFA, polyunsaturated fatty acid; SWP, silkworm pupae; Trp, tryptophan; WG, weight gain; Wf, fish final weight; Wi, fish initial weight.

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1. Introduction

The steady decline in catches of wild fish (FAO, 2014) and the increased demands for livestock and aquaculture feeds have resulted in a rapid decrease in the availability of fishmeal (FM) and fish oil (FO) and in their concurrent price increase (FAO, 2014). The cost of aquaculture feeds represents 40–70% of the cost of the fish produced (Wilson, 2002; Rana et al., 2009) and is especially high in the aquaculture of carnivorous fish that require large amounts of FM (Manzano-Agugliaro et al., 2012). Soya and other terrestrial plants rich in proteins and lipids have been introduced into the diet of aquaculture fish to replace FM and FO (Hardy, 2002; Espe et al., 2006; Gatlin et al., 2007). However, the presence of anti-nutritional factors in plant meals (Tacon, 1993; Francis et al., 2001; Ogunji, 2004; Collins, 2014), the potential problems of the inflammation of the digestive tract (Merrifield et al., 2011) and the decreased palatability of the meal (Papatryphon and Soares, 2001) are of concern. Moreover, the rapid growth in the human population has put pressure on the use of arable land (Doos, 2002), and the ecological footprint of these protein-rich plants, related to the amount of energy and water necessary for their production, may alter the sustainability of such alternatives to FM and FO (Naylor et al., 2009).

Since insects are part of the natural diet of both freshwater and marine fish (Howe et al., 2014; Whitley and Bollens, 2014) (Table 1), and because they are rich in amino acids, lipids, vitamins and minerals (van Huis, 2013) and leave a small ecological footprint (no need for arable land, low need for energy and water) (Oonincx and de Boer, 2012), they have been considered as potential alternatives to FM and FO. Moreover, insect larvae can rapidly transform low quality organic waste into good quality fertilizer (van Huis et al., 2013), thus reducing the final mass of manure by 50%, of nitrogen waste by 30–50%, and of phosphorus waste by 61–70% (Newton et al., 2005; Diener et al., 2009; van Huis et al., 2013). They also reduce the load of pathogenic bacteria in the microflora of manure (Erickson et al., 2004; Liu et al., 2008). Furthermore, the final product of this very efficient bioconversion of manure is an abundant amount of insect larvae or prepupae rich in proteins (40%) and lipids (30%) (Sheppard et al., 1994; Newton et al., 2005). Many insects (Lepidoptera, Diptera, Hymenoptera, Coleoptera, Trichoptera, Hemiptera, Odonata) also show antifungal activity and/or antibacterial peptides (Ravi et al., 2011) that may increase the shelf-life of insect-containing feeds (Zhao et al., 2010). For all these reasons, nutritional studies on the use of insects in livestock and aquaculture feeds (mainly for freshwater fish) have been conducted mainly in Asian, African and South American countries (Veldkamp et al., 2012). The present review article aims to describe the published results of experiments using insects (larvae, prepupae, pupae and adults) as FM and/or FO replacements in aquaculture feeds for freshwater and marine fish after briefly presenting the general requirements of the fish and the composition of the insects used in these studies. The review also attempts to establish the best insect candidates and optimal incorporation rates in the fish diets and discusses the potential hurdles and the different ways of improving the quality and acceptability of insect meal.