Chapter 6
Quality and Consumer Acceptance of Products from Insect-Fed Animals

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Abstract Fish and soybean meal are the most common protein sources in aquaculture and poultry feed ingredients, but these conventional sources are no longer sustainable and will be further limited by increasing prices. New and sustainable protein sources for animal feeds are necessary, and insects seem a promising, novel option due to their good nutritional profile and lower environmental impact. After a brief introduction, this chapter critically reviews the latest knowledge about the dietary use of insect meals in fish, shellfish and avian species. Particular focus is put on their impact on the flesh and meat of aquaculture and poultry products in terms of sensorial perception and quality traits. In general, analysis of sensory properties shows that for both products no differences were perceived if untrained panelists were involved in the sensorial analysis. Concerning meat and flesh quality, results are controversial, but a dramatic influence of insect meal fatty acid (FA) profile with a decrease in long chain n-3 FA content has been observed in both species. Moreover, an overview on the available data about consumer acceptance towards food products from insects-fed animals is provided.

Keywords Aquaculture · Alternative proteins · Animal origin food · Sensory · Egg · Insects · Meat · Poultry

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Abbreviations

DHA	Docosahexaenoic acid
EPA	Eicosapentaenoic acid
EU	European Union
FA	Fatty Acid
FM	Fish Meal
HI	Hermetia Illucens
IM	Insect Meal
MD	Musca Domestica
PAP	Processed Animal Proteins
SBM	Soybean Meal
SFA	Saturated Fatty Acids
TM	Tenebrio Molitor

Introduction

Fish meal (FM) and soybean meal (SBM) are the most common protein sources in aquaculture and poultry feed, but these conventional sources are no longer sustainable and will be further limited by increasing prices (Veldkamp and Bosch 2015). New and sustainable protein sources for animal feeds are necessary and insects seem to be promising alternatives due to their good nutritional profile and low environmental impact (Van Huis and Oonincx 2017).

The European Union (EU) Commission recently approved the use of Processed Animal Proteins (PAPs) from seven insect species for aquaculture feeds (Regulation (EU) 2017/893). Moreover, the EU Commission amended Regulation (EU) 68/2013 on the Catalogue of feed materials, introducing "terrestrial live invertebrates" or "dead invertebrates with or without treatment but not processed" as referred to in Regulation (EC) 1069/2009 (Regulation (EU) 2017/1017). Of course, these land animal products shall fulfil the requirements of the Regulation (EC) 1069/2009 and Regulation (EU) 142/2011 and may be subject to restrictions in use according to Regulation (EC) 999/2001.

Thus, under the current EU Regulations, PAPs from insects can only be used for aquaculture, while live or not processed dead insects can also be used as feed in in monogastric animals.

Outside of the EU, different regulations exist and other insect species may be used for feed purposes. Overall, there is great interest in using insects (raw or processed) for animal feed (Biasato et al. 2017, 2018; Dobermann et al. 2017; Henry et al. 2015; Józefiak et al. 2016; Makkar et al. 2014; Sánchez-Muros et al. 2014). The sections that follow provide an evaluation of the dietary use of insect meals (IM) in fish, shellfish and avian species, specifically their impact on sensorial perception and quality traits of the flesh and meat of aquaculture and poultry products.

Aquaculture Products

Due to the increasing interest in the use of IM in aquafeeds, a consistent number of nutritional studies have been carried out in both fish and shellfish species; their impact on product quality is reported in Table 6.1.

The effects of dietary IM inclusion on proximate composition and quality parameters of aquaculture products were investigated testing different inclusion levels of *Hermetia illucens* (HI) and *Tenebrio molitor* (TM) meals. Proximate composition of shrimp muscle and fillets of rainbow trout (raw and cooked) fed TM diets were evaluated; no differences were recorded in measures of moisture, protein and ash content (Panini et al. 2017; Iaconisi et al. 2018). Contrastingly, an increase in dry matter and ether extract contents of trout dorsal fillets was found by Renna et al. (2017) in fish fed the highest (50%) dietary HI larvae meal inclusion.

Concerning the quality parameters, studies carried out on blackspot seabream, gilthead seabream and rainbow trout fed with different TM meal inclusion levels reported no significant differences in some fillet quality parameters, such as water holding capacity and texture characteristics (Iaconisi et al. 2017, 2018; Piccolo et al. 2017). As far as the fish colour is concerned, TM diets may affect the colours of the fillet and skin of blackspot seabream. In particular, the highest redness index (a∗) in the skin ventral region and an increased yellowness (b∗) in the fillet epaxial region were found in fish-fed the maximum inclusion level of TM (Iaconisi et al. 2017). Conversely, results reported by Mancini et al. (2018) highlighted a decreased fillet yellowness in rainbow trout fed HI diet replacing 50% of FM. The authors explained this opposite trend with a modification of the fatty acid (FA) muscle profile related to a different FA profile of the IM utilised in the trials.

Since IM use in fish diets may lead to changes in fillet fatty acid composition, sensory properties of fish products can vary as well (in particular the aroma and flavour, which are directly linked to the dietary lipid-volatile components) (Turchini et al. 2007; Borgogno et al. 2017). In general, capability of perceiving sensory differences may depend on training of panellists. For instance, unaffected sensory parameters were perceived by both untrained and trained panellists in rainbow trout (Sealey et al. 2011) and Atlantic salmon (Lock et al. 2016) fed with HI prepupae and larvae meals, respectively, as partial or total replacement of FM. However, a more recent rainbow trout feeding trial involving untrained panellists did not highlight any significant differences for any selected parameters of taste and odour, while a significantly darker filet colour was identified in fish fed with HI meal compared to a control diet (Stadtlander et al. 2017). Contrastingly, significant changes in perceived intensity of aroma, flavour and texture descriptors of rainbow trout fed with HI meal as FM replacer were highlighted by Borgogno et al. (2017) who used trained panellists. Specifically, the dominance of metallic flavour characterised fillets of fish fed HI diets, demonstrating an unfamiliar flavour to the consumer. Nevertheless, the authors concluded that dietary IM inclusion did not induce the perception of off-flavours.

Table 6.1 Maximum level of FM substitution (and IM inclusion) and related impacts on flesh quality traits

Fish /Shellfish Species		Insect species tested	Max % of FM substitution	% IM inclusion	Major impacts on product quality	Reference
Atlantic salmon	*Salmo salar*	HI	100	5–10–25	Sensory testing of fillets of fish fed 10 and 25 IM inclusion level did not reveal any significant differences in odour, flavour/ taste or texture between groups	Lock et al. (2016)
Carp var. Jian	*Cyprinus carpio*	HI	100	3.5–14	No differences in proximate composition while HI inclusion decrease the n-3 highly unsaturated fatty acid composition in body of fish.	Zhou et al. (2018)
Rainbow trout	*Oncorhynchus mykiss*	HI	50	25–50	Significant changes in perceived intensity of aroma, flavor and texture. Dominance of metallic flavor characterized fillets of fish fed HI diets.	Borgogno et al. (2017) Renna et al. (2017) Mancini et al. (2018) Secci et al. (2018a)
Rainbow trout	*Oncorhynchus mykiss*	HI	50	50	No differences except a slightly darker coloration of fish fed HI were observed in a controlled panel test.	Stadtlander et al. (2017)
Rainbow trout	*Oncorhynchus mykiss*	HI	50	25–50	No significant difference were observed in a controlled panel test of fish fed the FM containing control diet as compared to fish fed the enriched HI or HI diets.	Sealey et al. (2011)

(continued)

Table 6.1 (continued)

Fish /Shellfish Species		Insect species tested	Max % of FM substitution	% IM inclusion	Major impacts on product quality	Reference
Rainbow trout	*Oncorhynchus mykiss*	TM	67	25–50	No negative effect on most quality traits of the fish flesh. The fatty acids C16:0, C18:1n9 and C18:2n6 increased whilst EPA and DHA progressively diminished in fillets when TM inclusion in feeds increased	Belforti et al. (2015) Iaconisi et al. (2018)
Gilthead seabream	*Sparus aurata*	TM	74	25–50	No negative effect on marketable indexes with a 25% of TM inclusion level. At 50% of TM inclusion level dressed yield was penalized.	Piccolo et al. (2017)
Blackspot seabream	*Pagellus bogaraveo*	TM	50	25–50	TM dietary inclusion affect some fillet quality parameters as ventral colour and muscle fatty acid profile.	Iaconisi et al. (2017)
Pacific white shrimp	*Litopenaeus vannamei*	TM	100	7.6–30.5	Colour and firmness were unchanged between the treatments. Dietary TM affected the lipid and fatty acid composition of shrimp muscle.	Panini et al. (2017)
Pacific white shrimp	*Litopenaeus vannamei*	TM	100	7.0–36	Maximum whole-body protein and lipid content achieved when HI inclusion was restricted to 29% and 15%, respectively.	Cummins Jr et al. (2017)

DHA Docosahexaenoic acid, *EPA* Eicosapentaenoic acid, *FM* fish meal, *HI Hermetia illucens*, *TM Tenebrio molitor*

In terms of lipid profile, insect larvae are characterized by poor contents of highly polyunsaturated fatty acids (PUFA). In fact, in land-based products (including SBM) and insects, the long chain FA (eicosapentaenoic acid, EPA and docosahexaenoic acid, DHA) are usually absent. Insect FA profiles may greatly vary with the insect species and substrates used for their rearing (Gasco et al. 2018), thus also affecting the fish products. Due to the high content of saturated fatty acids (SFA) of HI, freshwater fish fed with increasing levels of HI meal showed increased contents of SFA (mostly lauric acid, C12:0) and decreased contents of valuable PUFA (both n-3 and n-6) (Renna et al. 2017; Mancini et al. 2018; Secci et al. 2018a; Zhou et al. 2018). Contrastingly, TM is characterised by high contents of oleic, linoleic and palmitic acids (Gasco et al. 2018). Fish fed diets including high levels of TM meal showed increased n-6 PUFA contents at the expense of n-3 polyunsaturated content (Belforti et al. 2015; Iaconisi et al. 2017, 2018), with a consequent reduction of the Σn-3/Σn-6 FA ratio and a worsening of the atherogenicity and thrombogenicity indexes.

Compared to other aquaculture products such as shellfish (in particular shrimp), dietary IM inclusion and their effects on product quality are poorly investigated. So far only a couple of papers have investigated the use of TM and HI in diets for Pacific white shrimp (*Litopenaeus vannamei*). Panini et al. (2017) concluded that dietary TM meal inclusion did not affect the Pacific white shrimp muscle quality, even if inclusion levels above the 25% FM substitution showed increased lipid and decreased PUFA muscle contents. Contrastingly, Cummins et al. (2017) tested different inclusion levels of HI meals and showed that the maximum whole-body lipid content could be achieved with a 15% of inclusion, given, however, no information about the FA profile of these products.

Poultry Products

Despite increasing interest in the use of IM in poultry feeds (in addition to fish feeds), a limited number of studies assessing products quality has been carried out until now. The current scientific research that has highlighted the impact of IM use on carcass characteristics and meat quality products are reported in Table 6.2.

Concerning meat quality, results are controversial. Cullere et al. (2016) observed that the redness index in the breast meat of broiler quails was affected by increasing dietary inclusion levels of HI larva meal. However, a partial substitution (25% or 50%) of dietary soybean protein with TM and HI meals in Barbary partridges (*Alectoris barbara*) has been reported to not affect the pH and colour of the raw meat, even if the presence of IM seemed to increase the yellowness index of the cooked meat (Secci et al. 2018b). Contrastingly, Altmann et al. (2018), Pieterse et al. (2018) and Leiber et al. (2017) did not find any significant effects of dietary HI meal inclusion on broiler meat colour. The inclusion of MD larva meal in broiler diets has also been associated with a significant decrease in breast muscle lightness (Pieterse et al. 2014). However, Bovera et al. (2016) did

Table 6.2 Maximum level of SBM substitution (and IM inclusion) and related impacts on egg and meat quality traits

Avian species	Insect species	Max % of SBM/FM substituted	% IM inclusion	Days of feeding	Major impacts on product quality	Reference
Barbary partridges	HI TM	68 SBM	12–22 TM 10–19 HI	64	No differences in the whole body composition except for the ash content.	Secci et al. (2018b)
					The carcass weights of all the insect groups were higher than the SBM group.	Loponte et al. (2017)
Broiler chickens	BM MD TM	100 SBM	7.8 BM 8.0 MD 8.1 TM	35	Tenderness and juiciness of meat were higher in TM group compared to the control and other treatments.	Khan et al. (2018)
Broiler chickens	HI	50 SBM	11.9–14.5	34	HI meal results in a product that does not differ from the standard fed control group, with the exception that the breast filet has a more intense flavour that decreases over storage time.	Altmann et al. (2018)
		49 SBM	7.8	75	Regarding quality parameters, only cooking loss was increased with the HI plus pea protein diet compared with the control.	Leiber et al. (2017)
		64 SBM	5–10–15	49	Replacement of SBM and FM with HI meal did not affect aroma or taste of cooked breast meat.	Onsongo et al. (2018)
		Not specified	5–10–15	32	No significant differences for pH, colour, thaw loss and cooking loss as well on the sensory characteristics (aroma, flavour, juiciness and tenderness) of the breast muscle of the broilers fed HI meal.	Pieterse et al. (2018)
Broiler chickens	MD	100 FM	10	32	Meat quality parameters were not affected except for drip loss that were lowest in HI meal treated group. Higher sustained juiciness values was found in chicken larvae fed.	Pieterse et al. (2014)

(continued)

Table 6.2 (continued)

Avian species	Insect species	Max % of SBM/FM substituted	% IM inclusion	Days of feeding	Major impacts on product quality	Reference
Laying hens	HI	100 SBM	17	147	Hens fed the insect-based diet(HIM) produced eggs with a higher proportion of yolk than the group fed the SBM group. HIM was associated with redder yolks, richer in γ-tocopherol, lutein, β-carotene and total carotenoids than SBM yolks.	Secci et al. (2018c)
Laying hens	HI	41 SBM	5–7.5	182	Hens fed the HI based diet linearly increased yolk color, egg shell-breaking strength and egg thickness.	Mwaniki et al. (2018)
Laying hens	HI	39 SBM	3.5–5–6.5	112	Hens fed HI diet showed higher egg production, egg weight and values of Haugh unit and egg shell thickness compared to those of the control.	Park et al. (2017)
Quail	HI	24.8 SBM	10–15	28	Breast meat weight and yield did not differ while the inclusion of HI meal reduced meat pHu. Meat proximate composition, cholesterol content and oxidative status remained unaffected by HI supplementation as well as its sensory characteristics and off-flavours perception.	Cullere et al. (2016, 2018)

BM Bombyx mori, *FM* Fish meal, *HI Hermetia illucens*, *MD Musca domestica*, *SBM* soybean meal, *TM Tenebrio molitor*

not find any significant effects on the colour of raw and cooked meat, or on the skin of broiler chickens, also showing that consumers could accept the meat from broilers fed with TM meal.

Studies on the effects of dietary IM inclusion on poultry meat proximate composition also conflict. Cullere et al. (2018), Pieterse et al. (2018) and Secci et al. (2018b) did not report any significant effects on meat chemical composition of broiler quails, chickens or Barbary partridges fed diets with either HI or TM meals. Contrastingly, Ballitoc and Sun (2013) reported the highest percentage of breast fat content in broiler chickens fed with the highest level of dietary TM meal inclusion.

In terms of sensory characteristics of poultry products, research conducted in Nigeria showed that meat obtained from broilers fed MD diets did not reveal any distinctive organoleptic qualities, and was accepted by consumers (Awoniyi 2007). Cullere et al. (2018) and Onsongo et al. (2018) did not report any defects or off-flavour, nor aroma or taste problems, that could negatively influence the consumer acceptability of meat obtained from broiler quails or chickens fed different inclusion levels of HI. Similarly, Khan et al. (2018) reported that different IM products did not affect meat taste or flavour, but tenderness and juiciness were higher in the TM group compared to the control and other diets. Contrastingly, Altmann et al. (2018) showed that breast meat of broiler fed diets containing HI meals had a more intense flavour that decreased over storage time. Finally, Pieterse et al. (2014) found that the sensory profile of meat derived from chickens fed with diets containing MD larvae meal was slightly different from the control group because of a higher perception of metallic aroma and aftertaste, but a higher sustained juiciness and a lower mealiness in the mouth. The authors also reported that this specific aroma and aftertaste could potentially be attributed to the increased iron content of the larvae meal.

Like with fish, the use of IM in poultry feeds can dramatically influence the FA profile of poultry meat. Cullere et al. (2018) showed that dietary HI meal inclusion greatly affected the FA profile of Japanese quail breast meat. In particular, increasing levels of HI larvae meal lowered the healthiness of the meat as saturated fatty acids (SFA) increased at the expense of polyunsaturated fatty acids (PUFA). In a recent study by Secci et al. (2018b) about Barbary partridges fed diets containing IM in partial substitution of SMB, the HI and TM groups showed significantly higher oleic acid (C18:1n-9) and lower palmitic acid (C16:0) contents than the SBM group. The authors also highlighted that dietary HI meal inclusion induced a significant increase in lauric acid (C12:0) and palmitoleic acid (C16:1n-7) contents.

Concerning laying hens, Secci et al. (2018c) recently tested the effects of total replacement of SBM with HI larva meal in laying hens' diets (Lohmann Brown Classic) for 21 weeks, observing a higher proportion of yolk in the eggs, as well as higher amount of γ-tocopherol, lutein, β-carotene and total carotenoids, in the HI group. In another study, Mwaniki et al. (2018) reported that including up to 7.5% of defatted HI larvae meal in a corn–SBM diet for pullets (19 to 27 wk. of age) resulted in an increased yolk colour, egg shell-breaking strength and thickness. Hens fed diets containing HI have also been reported to show higher egg production and weight than those fed with a control diet (Park et al. 2017). Contrastingly, dietary HI larvae meal utilization in free range laying hens may result in a reduction of egg weight, shell weight and thickness, and yolk colour (Ruhnke et al. 2018). Finally, MD maggot meal has been reported to replace 50% of FM in diets for hens (5% of inclusion) without any adverse effects on egg production and shell strength (Agunbiade et al. 2007). However, the total replacement was deleterious to hen-egg production (Agunbiade et al. 2007).

Consumer Acceptance Towards Food Products from Insects-Fed Animals

Another important aspect in facing the impact of innovative feed ingredients in animal nutrition is represented by the consumer attitude towards novel food products. The determining factors in the buying process for several novel foods have been reported to mainly depend on the type of innovation and its market acceptance (Barrena and Sánchez 2012).

So far, data about consumer attitudes towards the utilization of insects in animal feeding are still lacking. In the first available survey involving 1300 consumers across 71 countries in the UK, EU and the Far East (East Asia, Russian Far East and Southeast Asia), the EU-funded PROteINSECT project showed that 73% of consumers were willing to eat fish, chickens or pork from animals fed on a diet containing insect protein. Furthermore, over 80% of people surveyed wanted to know more about insect utilization, with 64% recognizing no or low risk to human health in eating farmed animals fed insect meal (PROteINSECT 2016).

In a more recent survey involving 82 people, Verbeke et al. (2015) reported that 68% of the interviewed farmers, agriculture sector stakeholders, and citizens from Belgium were willing to accept the use of insects as feed ingredients in animal nutrition, especially for fish and poultry feed. The most relevant perceived benefits for the citizens were that the use of insects might allow a better exploitation of organic waste and lower dependence on foreign protein sources, as well as an improvement in the sustainability of livestock production and reduction of the ecological footprint of livestock (Verbeke et al. 2015).

In the same year, Neves (2015) recruited 363 and 303 Norwegian and Portuguese consumers, respectively, to test their acceptance of insects as feed. The obtained results revealed high acceptance to use insects to feed fish in both countries, with significantly higher acceptance among Norwegian consumers. A subsequent French survey conducted with 327 participants showed that the majority of consumers were willing to accept trout fed with insects when they have been informed of the environmental impact of the conventional feeding method and that the trout price was lower (Bazoche and Poret 2016).

The most recent European survey included a total of 4 stakeholders and 180 consumers from Scotland and was focused on the attitude towards the incorporation of cultured insect larvae- (maggots) derived feed materials into commercially formulated fish feeds for the Scottish salmon farming sector (Popoff et al. 2017). The results were promising for both survey categories. First, feed and salmon producers were generally open to the use of insect meals, provided the feeds were safe, reliable, and competitive and there were additional value benefits for producers. Second, the majority of consumers were also prepared to eat insect-fed fish with no concerns, while the 36% indicated specific conditions of unchanged price, safety and taste. It is also important to underline that most people favoured supermarket food and vegetable waste as rearing materials for insects, with only a minority considering animal manure, abattoir waste and human sewage suitable, thus also influencing their willingness to pay for the fish (Popoff et al. 2017).

Mancuso et al. (2016) recently explored the attitude and behaviour of Northern-Italian consumers of farmed fish fed with insects. Authors considered the different phases of the purchasing process, from interest in marine ecology and awareness of limited resources for fish feeding, to attitudes about eating finfish products if fed with insects, and finally to the decision to purchase. According to their findings, almost 90% of consumers were interested in research on more sustainable sources of feed used in aquaculture, also showing a positive attitude towards insect meals as feed in fish farming. In regards to purchasing activity, most of the respondents (76%) intended to buy and eat farmed fish even those fed insect meals, so long as hygiene requirements were met. About half of respondents (46.2%) also believed that the price would be the same as traditional fish products, whereas 29.2% and 23.8% thought that the product would have a lower or higher price, respectively, when compared to conventional (Mancuso et al. 2016). Another Italian survey evaluated the willingness of 341 consumers (students and employees from a university and ordinary citizens) to adopt insects as part of animal and human diets (Laureati et al. 2016). According to their findings, approximately 53% of the consumers appeared to be ready to incorporate insects into animal diets and to eat fish and livestock reared with insect-based feed. This outcome was attributed to the fact that fish and many other farmed animals (such as poultry and pigs) eat insects when they are reared in natural environments. Therefore, this phenomenon could have made the consumers more willing to accept the systematic use of insects or derivatives (e.g., meals) in farming. Interestingly, males were significantly more willing than females to consume products from insect-fed animals. Younger consumers, as well as people with a higher level of education about the topic (i.e., university students and employees) were also significantly more willing to accept insects as feed (Laureati et al. 2016).

Conclusions and Future Perspectives

In light of the considerations made in the previous sections, it is clear that in order to cope with an increasing global population and changing diets, an urgent supply of protein from sustainable sources for animal feeding is needed, especially in Europe where 70% of the protein is currently imported for animal feed purposes. Because of their good nutritional profile and lower environmental impact, the introduction of insects in the formulation of aquaculture and poultry feed ingredients should be considered as a beneficial long-term solution for sustainability and environmental impact. Available scientific literature demonstrates that from a technical point of view a partial or total replacement of conventional protein sources by means of insect proteins is feasible with minimal impact on the sensorial and quality characteristics of the animal food products. However, a potential barrier against the use of insect proteins in animal feed is their public acceptance by consumers. In Western society, the lack of a cultural history of eating insects makes them a novel food. It is noteworthy that available consumer perception surveys showed a high level of support for insects as a protein source in animal feeding, as well as a desire for more information about the topic. However, in order to facilitate consumer acceptance towards the use of insect proteins in animal feeds, it is important that the introduction of this novel source be carried out in a transparent manner. In particular, consumers will have to be consulted and informed throughout the entire production process, in order to avoid the communication bias committed in the past, for example, in the case of protein sources deriving from GMO crops.

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