Insects as Raw Materials in Compound Feed for Aquaculture

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Abstract Already in the early phases of the development of an European insect industry, aquafeed was suggested as one of the first animal feeds where insect products could be implemented. Since then, substantial progress has been made by the research community and feed producers to test various types of insect species and insect products as part of a complete feed for aquaculture. These (mostly extruded) feeds are typically high in energy and protein content which demands specifics characteristics of the raw materials. The role insects, high in protein and lipids, can play in these diets will be reviewed and discussed in this chapter. We will shortly touch on topics like the effect of insect feeding substrate, insect processing and chitin that all can have an effect on insect meal. Finally, feed safety considerations related to the use of insects in aquafeeds will be reviewed and discussed.

1 Introduction

Compound feed contains macro- and micronutrients in levels that fulfil the animal's requirements for healthy growth under intensive rearing conditions. Compound feed normally contains animal- and/or plant-based feed materials to which micronutrients (vitamins, minerals) are added. The most used feed ingredients are fishmeal, krill meal, soy protein concentrate, corn gluten meal, wheat gluten, fish oil and rapeseed oil amongst others. Animal by-products, like feather meal or blood meal are also used (not in Norway) and novel feed materials are investigated like, seaweed, microalgae, bacterial protein meal and insects. Diets for carnivorous fish like

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rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*) are high-energy diets, characterized by high contents of lipids and protein, and low levels of carbohydrates. Animal-based feed ingredients, like insects, fit these constraints much better then vegetable-based feed ingredients. The nutrient content of various insect species has been widely studied and is reviewed in several articles (Rumpold and Schluter 2013; Barroso et al. 2014; Makkar et al. 2014; Sanchez-Muros et al. 2014; Henry et al. 2015). Fish prey on insects in their natural environment and to include insects in a compound feed is self-evident from a natural perspective. However, also from a nutritional perspective insects can be a valuable feed ingredient and will be discussed in the following sections.

2 Inclusion of Insect Raw Materials in Compound Feed for Fish

A large number of insect species can potentially be considered for their inclusion in fish diets. However, the interest towards the use of insect ingredients in aquafeeds focusses mainly around a few insect species that can be produced on a large scale. The investigations conducted so far mainly concern the use of larvae meals obtained from *Tenebrio molitor* (TM), *Hermetia illucens* (HI) and *Musca domestica* (MD). While a relatively large number of research articles exists on insect meals in warm water fish species (Henry et al. 2015), very few studies have investigated the effects of insect meals (IM) in salmonids (Table 1) or marine species (Table 2).

The results of the existing studies differ, depending on fish species considered, IM inclusion levels and types, and feed formulation. Including a new ingredient means replacement of another ingredient in the diet. In most studies, fishmeal (FM) is replaced; however other studies replaced plant-based ingredients, resulting in not directly comparable results. Finally, a replacement of FM by IM is often expressed as % replacement of FM. Since the amount of FM varies between studies, direct comparisons on % replacement is not always possible.

2.1 Growth Performance and Feed Utilisation

The use of IM in salmonid diets was already investigated in the 1980s (Akiyama et al. 1984) with the aim of stimulating feed ingestion or palatability. A part of the FM was substituted by low levels (5%) of silkworm pupae or earthworm powder in swim-up fry diets. The use of earthworm powder resulted in a weight gain (WG) and feed efficiency improvement of 30% and 39% respectively. Silkworm meal slightly improved feed efficiency while neither source increased the palatability of the fish diet, measured as daily food consumption.

Table 1 Growth performances of salmonids fed insect meals diets compared to FM (or other protein sources) control diet

Specie	Insect meal	IBW (g)	Rearing substrate	Insect processing	FM in diet (%)	Other protein source (%)	% CP in diet (%DM)	FM (or other protein source) substitution (%)	% Insect meal dietary inclusion	FBW	WG%	WG	FC	FR	FE	PER	FCR	SGR	Reference
Chum salmon (*Oncorhynchus keta*)	Control	0.2	–	–	69.2	–	45.63	–	–	–	–	b	a	–	c	–	–	–	Akiyama et al.(1984)
	SW		–	Commercial products	64.8		49.53	6.36	5	–	–	b	b	–	b	–	–	–	
	EW				64.4		46.44	6.94	5	–	–	a	c	–	a	–	–	–	
Rainbow trout (*Oncorhynchus mykiss*)	Control	22.5	–	–	36.0	CGM (8) SBM (16)	39.1	–	–	a	–	a	nd	–	–	–	a	–	St-Hilaire et al. (2007)
	HI		Pig manure	–	27.0		37.4	25	14.9	ab	–	ab	nd	–	–	–	a	–	
	HI		Pig manure		18.0		37.5	50	29.8	b	–	b	nd	–	–	–	b	–	
	MD		Cow manure		27.0		41.0	25	9.2	b	–	b	nd	–	–		a	–	
Rainbow trout (*Oncorhynchus mykiss*)	Control	146	–	–	29.1	CGM (7) SBM (16) WGM (7.8)	46.00	0	0	–	a	–	nd	–	–	–	nd	–	Sealey et al. (2011)
	NHI		Cow manure	Freeze grinded + dryied full fat prepupae	21.8		48.50	25	16.4	–	b	–	nd	–	–	–	nd	–	
	NHI				14.5		50.40	50	32.80	–	b	–	nd	–	–	–	nd	–	
	EHI		Cow manure + fish offal		21.8		51.20	25	18.12	–	ab	–	nd	–	–	–	nd	–	
	EHI				14.5		52.50	50	36.24	–	ab	–	nd	–	–	–	nd	–	
Rainbow trout (*Oncorhynchus mykiss*)	Control	115.6	–		75	–	45.2	0	0	nd		nd	–	a	–	b	a	b	Belforti et al. (2015)
	TM		Wheat bran	Oven dried (full fat)	49	–	44.6	34.66	25	nd		nd	–	ab	–	a	b	a	
					25	CGM (5)	44.8	66.67	50	nd		nd	–	b	–	a	b	a	

(continued)

Table 1 (continued)

Specie	Insect meal	IBW (g)	Rearing substrate	Insect processing	FM in diet (%)	Other protein source (%)	% CP in diet (%DM)	FM (or other protein source) substitution (%)	% Insect meal dietary inclusion	FBW	WG%	WG	FC	FR	FE	PER	FCR	SGR	Reference
Atlantic salmon (*Salmo salar*)	Control	247	Food organic waste streams		20.0	WGM (20) SPC (20)		0	0				–	–	–	–		–	Lock et al. (2016)
	HIA			Dried partially defatted larvae meals	15.0	WGM (20) SPC (19.7)		25	5				–	–	–	–		–	
					10.0	WGM (19.4) SPC (20.2)		50	10				–	–	–	–		–	
					0.0	WGM (19.1) SPC (22.3)		100	25	*			–	–	–	–	*	–	
	HIB				15.0	WGM (20) SPC (20.8)		25	5	*			–	–	–	–	*	–	
					0	WGM (17.5) SPC (21.9)		100	25	*	*		–	–	–	–	*	–	

Specie	Insect meal	IBW (g)	Rearing substrate	Insect processing	FM in diet (%)	Other protein source (%)	% CP in diet (%DM)	FM (or other protein source) substitution (%)	% Insect meal dietary inclusion	FBW	WG%	WG	FC	FR	FE	PER	FCR	SGR	Reference
Rainbow trout (*Oncorhynchus mykiss*)	Control	179	Plant substrate	Dried partially defatted larvae meal	60	WM (4)	45.20	0	0	nd	–	nd	–	nd	–	nd	nd	nd	Renna et al. (2017)
	HI				45		44.86	25	20	nd	–	nd	–	nd	–	nd	nd	nd	
					30		45.00	50	40	nd	–	nd	–	nd	–	nd	nd	nd	

FM Fishmeal, *SW* Silkworm, *EW* Earthworm, *HI* Hermetia illucens, *MD* Musca domenstica, *NHI Hermetia illucens* prepupae reared in normal cow manure, *EHI Hermetia illucens* prepupae reared in cow manure enriched with fish offal, *HIA Hermetia illucens* larvae meal containing 25.5 lipid, *HIB Hermetia illucens* larvae meal containing 17% lipid, *TM Tenebrio molitor, SBM* soybean meal, *CGM* Corn gluten meal, *WGM* Wheat gluten meal, *SPC* Soy protein concentrate, *CP* crude protein, *IBW* Initial body weight (g), *FBW* Final body weight (g), *WG* Weight gain (g): FBW – IBW, WG (%) = FBW – IBW/ IBW * 100; *FC* Feed consumption = grams feed consumed per 100 g body weight per day, *FR* feeding rate (%/day) = [total feed supplied (g DM) * 100%/number of feeding days)]/e(lnIBW + lnFBW)*0.5], *FE* Feed efficiency = WG/ dry food intake, *PER* Protein efficiency ratio = wet weight gain (g)/total protein intake (g), *FCR* Feed conversion ratio = Ingested feed (g)/wet weight gain (g), *SGR* Specific growth rate (%/day) = {(ln final fish weight ± ln initial fish weight)/days}* 100. Columns with different superscripts (a, b) are significantly different at $P < 0.05$; * Significantly different from control diet ($P < 0.05$) - no information; *nd* no differences

Table 2 Growth performances of marine species fed insect meals diets compared to FM (or other protein sources) control diet

Specie	Insect meal	IBW (g)	Rearing substrate	Insect processing	FM in diet (%)	Other protein source (%)	% CP in diet (%DM)	FM (or other protein source) substitution) (%)	% Insect meal dietary inclusion	FBW	WG%	WG	FIFC	FR	PER	FCR	SGR	Reference
Turbot (*Psetta maxima*)	Control	54.9	–	–	68.70	WP (2) BM (5)	54.80	0	0	nd	–	–	a	–	–	a	a	Kroeckel et al. (2012)
	HI		Green house waste	Frozen, partially defatted, oven dried prepupae	55.00		54.90	20	16.5	nd	–	–	a	–	–	a	b	
					42.20		53.70	40	33.2	nd	–	–	a	–	–	ab	b	
					30.50		53.90	55	48.6	nd	–	–	b	–	–	b	c	
					18.00		53.3	74	64.0	nd	–	–	b	–	–	c	d	
					8.00		52.70	88	75.6	nd	–	–	c	–	–	d	e	
European sea bass (*Dicentrarchus labrax*)	Control	5.22	–		70	WGM (5)	59.56	0	0	a	–	a	–	a	nd	nd	a	Gasco et al. (2016)
	TM		Wheat bran	Oven dried (full fat)	45	WGM (7.5) CGM (2.8)	59.04	35.71	25	ab	–	ab	–	ab	nd	nd	ab	
					20	WGM (15)	59.54	71.42	50	b	–	b	–	b	nd	nd	b	
Gilthead sea bream (*Sparus aurata*)	Control	105	–		50	15 (CGM)	46.05	0	0	b	b	–	–	–	b	a	b	Piccolo et al. (2017)
	TM		Wheat bran	Oven dried (full fat)	33.3	12.5 (CGM)	45.69	33.4	25	a	a	–	–	–	a	b	a	
					13	13 (CGM)	45.16	74	50	b	b	–	–	–	b	a	b	

FM Fishmeal, *HI Hermetia illucens*, *TM Tenebrio molitor*, *WP* Wheat protein, *BM* Blood meal, *CGM* Corn gluten meal, *WGM* Wheat gluten meal, *CP* crude protein, *IBW* initial body weight (g), *FBW* Final body weight (g), *WG* Weight gain (g): FBW – IBW; WG (%) = FBW – IBW/ IBW * 100; *FC* Feed consumption = grams feed consumed per 100 g body weight per day, *FR* feeding rate, (%/day) = [total feed supplied (g DM) * 100%/number of feeding days)]/e(lnIBW + lnFBW)*0.5]; *PER* Protein efficiency ratio = wet weight gain (g)/total protein intake (g), *FCR* Feed conversion ratio = Ingested feed (g)/wet weight gain (g)/, *SGR* Specific growth rate (%/day) = {(ln final fish weight ± ln initial fish weight)/days}* 100. Columns with different superscripts (a, b, c) are significantly different at $P < 0.05$. - no information; *nd* no differences

St-Hilaire et al. (2007) investigated the use of a full fat pre-pupae HI meal used in partial substitution of FM and fish oil (FO) in the diet of rainbow trout. HI meal was included at two levels (15 and 30%) leading to a FM substitution of 25% and 50% and to a FO substitution of 36 and 72% respectively. No significant differences on growth performances were reported at the lowest level of inclusion allowing a valuable FO saving. St-Hilaire et al. (2007) suggested that above this level, the chitin contained in the pre pupae may have decreased the digestibility, thus the availability of nutrients, resulting in lower fish performances. On the other hand, the dietary inclusion of HI meal lead to a modification of the dietary fatty acid profile (increase and decrease of saturated and polyunsaturated fatty acids respectively) that could have influenced lipid digestibility. In the same trial, authors studied the effects of a whole MD larvae meal included at 9.2% in the fish's diet (25% of FM substitution). The inclusion resulted in a decrease of production parameters (St-Hilaire et al. 2007). Renna et al. (2017) showed that a partially defatted HI larvae meal can be used as feed ingredient in rainbow trout diets up to 40% of inclusion level (50% of FM substitution) without impacting growth performance. Sealey et al. (2011) highlighted the possible influence of larva rearing substrate on the quality of the insect meal in a trial with rainbow trout. IM produced from HI larvae fed a diet enriched with fish offal performed better than IM produced from HI larvae fed a diet without the fish offal enrichment. Rainbow trout fed a diet with the enriched HI meal (at 50% FM replacement) performed equally well as the control FM based diet, whilst the non-enriched HI meal performed less at already 25% FM replacement.

A full fat TM larvae meal was tested as a FM substitution (up to 50%) in rainbow trout diets by Belforti et al. (2015). No significant changes in fish performance parameters were found up to 50% FM replacement. A reduced voluntary feed intake was reported with the increase of TM meal. The effects of dietary FM replacement (0, 25%, 50% and 100%) by super worm (*Zophobas morio*) meal on rainbow trout fingerlings growth performance was investigated by Doğankaya (2017). Fish fed diets containing up to 25% of FM substitution performed better than the fish fed the control diet, while no differences were observed between 0% and 50% of FM substitution. Highest IM level induced a dramatic worsening in performance parameters.

Concerning marine species, Kroeckel et al. (2012) tested partially defatted HI prepupae meal in diets of juvenile turbot (*Psetta maxima*), and found a general worsening of performances at the inclusion levels higher than 33%. Moreover, authors found a decrease of feed intake with increasing HI meal incorporation, due to low palatability. Authors suggested that the presence of chitin might have influenced the feed intake, availability, and digestibility of the nutrients and therefore growth performance. Nevertheless, as HI was produced on local greenhouse waste streams, the authors concluded that it could be a sustainable alternative protein source in partial substitution of FM (Kroeckel et al. 2012). Karapanagiotidis et al. (2014) evaluated a pre-pupae full fat HI meal (crude protein, CP: 31.6%; either extract, EE: 27.2) in gilthead seabream (*Sparus aurata*) diets. Four diets were formulated substituting FM (0, 9%, 17% and 25%) with HI meal at 0%, 9.5%, 19.4%

and 27.6% of HI inclusion. Fish fed diets containing HI meal recorded a significant decrease in final fish weight and WG due to a significant decrease of total feed consumption. On the other hand, feed conversion rate (FCR), protein efficiency ratio (PER) and protein retention as well as specific growth rate (SGR) parameters did not show differences among treatments.

Gasco et al. (2016) evaluated the effects of dietary inclusion of a full-fat TM larvae meal on European sea bass (*Dicentrarchus labrax*) juveniles. Dietary TM meal inclusion level of 50% led to a worsening of final body weight, WG, SGR and feeding rate (FR). Using the same substitution protocol and the same full-fat TM larvae meal, Piccolo et al. (2017) found improved final weight, SGR, PER and FCR in fish fed 25% of TM meal dietary inclusion.

The importance of insect processing becomes evident in a study by Lock et al. (2016). Two different HI meals (IMA and IMB), obtained through different nutrient isolation and processing techniques, were evaluated in diets for Atlantic salmon. IMA substituted 25, 50 and 100% of FM in the control diet while IMB was used at 25 and 100% FM replacement rate. Diets containing IMA performed equally well as the control group at all inclusion levels, however diets produced with IMB reduced fish performance parameters already at 25% FM replacement.

2.2 Whole Body and Fillet Composition

The influence of the use of IM on whole body composition (WBC) and fillet composition is not univocally. While an effect on the protein content has been shown (Belforti et al. 2015), the majority of the existing studies report a decrease in lipid and moisture increase in either WBC or fillet of fish when fed diets containing IM (St-Hilaire et al. 2007; Sealey et al. 2011; Kroeckel et al. 2012; Belforti et al. 2015). A reduced fat and energy digestibility of some IM could be the reason for the observed decreasing carcass fat content. Conversely, Akiyama et al. (1984) reported an increase in body energy reserves using earthworm. This effect was considered as very valuable as that could increase the fingerlings survival once released. Renna et al. (2017) found an increase of fat content in rainbow trout fillets using a partially defatted HI meal, but only at the highest level of inclusion. Similar results have been found in feeding Atlantic salmon diets containing high levels of defatted HI meal (Lock et al. unpublished results). High HI meal inclusion results in a higher saturated lipid content of the whole fish and fillet.

It has been ascertained that the dietary fatty acid (FA) profile dramatically influences the fish FA composition. IM are rich in saturated and monounsaturated FA, and do not contain the marine omega-3 long chain polyunsaturated FA (PUFA) such as eicosapentaenoic acid (EPA, C20:5 n3) or docosahexaenoic acid (DHA, C22:6 n3), which are well known for their beneficial effects on human health. St-Hilaire et al. (2007) reported a deterioration in fish nutritional quality using both MD and HI meals in diets for rainbow trout. The inclusion of IM led to a significant decrease of n3 FA such as EPA and DHA, which is confirmed in other studies (Belforti et al.

2015; Gasco et al. 2016; Lock et al. 2016; Renna et al. 2017). Sealey et al. (2011) and Liland et al. (under revision) were able to modify the HI meal FA profile by enriching the larvae rearing substrate with fish offal and seaweed, respectively. Sealey et al. (2011) performed a trial with trout using the enriched HI meal and reported increased EPA (significant) and DHA (not significant) content in the fish. Up to 20% inclusion of a de-fatted HI meal while maintaining FO in the diet does not change the FA profile of trout compared to fish fed a control diet based on FM and FO (Renna et al. 2017).

2.3 Sensory Analyses

As the change of body composition and fatty acid profile can influence fish flavour, aroma and consumer acceptance (Turchini et al. 2011), some studies investigated the effect of diets containing IM on the sensory aspects of the fish fillet.

In a triangle difference test, untrained panellists did not highlight different sensory perception in samples of fillets of trout fed diets containing HI meal (enriched or not using fish offal in larva rearing substrate) compared to a FM based diet with no inclusion of HI pre-pupae meal (Sealey et al. 2011). Lock et al. (2016) investigated the sensory attributes of fillets of fish from diets containing FM (control) or 25% of inclusion of HI meal (100% of FM substitution) after 105 days of feeding. Trained panellists were asked to score attributes such as odour, taste and flavour, and texture scoring them in a scale from 1 to 9. The analysis did not highlight any significant differences in odour, flavour/taste or texture between groups.

Borgogno et al. (2017) utilised descriptive analysis (DA) and Temporal Dominance of Sensations (TDS) to investigate the effects of replacing 25 and 50% of FM with HI meal on sensory properties of rainbow trout. Results indicated that diets significantly affected fillets sensory profile. In fact, significant changes in perceived intensity of aroma, flavour and texture descriptors as a function of diet composition was indicated by DA. Concerning TDS, the first sensations perceived as dominant were related to texture attributes, followed by flavours. Dominance of fibrousness (or toughness) decreased with the increasing of HI meal in diet. Boiled fish, algae flavours and umami taste clearly dominated the fish fed control diet dynamic profile. The onset of metallic flavour dominance characterized fish fed diets where FM was substituted by 25 and 50% of HI meal. No differences in physical parameters were detected. Principal component analysis highlighted the relationship between sensory attributes and physico-chemical parameters.

2.4 Chitin

It is commonly assumed that, due to its complex matrix, insect chitin is poorly digestible by fish, albeit the chitinase activity has been observed in some fish species (Henry et al. 2015). It has been hypothesized that these matrix forms of chitin may reduce the access of chitinases or proteinases to their substrates and thus prevent the absorption of proteins and lipids by the intestine. As such, reducing lipid and protein digestibility resulting in a subsequent reduction in nutrient utilization and fish growth performance (Belforti et al. 2015; Henry et al. 2015; Gasco et al. 2016). Some studies investigated the nutrient apparent digestibility coefficients (ADC) of diets containing IM. In general a lower crude protein ADC is found compared to FM based diets (Kroeckel et al. 2012; Belforti et al. 2015). Nevertheless, not all studies find a decrease in ADC (Lock et al. 2016; Renna et al. 2017), highlighting once again the high variability in type and quality of insect meal available on the market.

Chitin as a stimulant of intestinal function, much like a fibre, has also been suggested. The use of alternative protein sources has often showed to induce histological changes of the fish gastrointestinal tract (Merrifield et al. 2009; Gai et al. 2012; Oliva-Teles et al. 2015). Very few studies have investigated this aspect using insect meals and results obtained so far are promising as no negative effects are reported (Lock et al. 2016; Doğankaya 2017; Renna et al. 2017).

3 Feed Safety

Feed safety regulations are in place to secure that feed and feed materials do not pose any danger to human health, animal health or the environment, aiming to provide healthy and safe food products to the public. To achieve this, the European Union has set maximum allowed levels for undesirable substances in animal feed and feeding stuffs (EC Directive 2002/32 and amendments) (EU 2002). This covers a wide range of toxic compounds such as heavy metals, arsenic, polychlorinated biphenyl (PCBs), pesticides, plant and fungal toxins, amongst others. Safety considerations need to be taken into account when insects are destined to animal feed.

The uptake of contaminants by insects in the wild is well known, therefore they have been successfully used as bioindicators for environmental pollution (Azam et al. 2015). The chemical safety of farmed insects for feed and food purposes has been reviewed (Belluco et al. 2013; Charlton et al. 2015; van der Spiegel et al. 2013). Although little data is available, major potential chemical hazards associated with farmed insects are heavy metals, and in particular cadmium. Accumulation of metals in insects is dependent on species, life stage, and metal considered. Larval stages of insects have been shown to contain higher concentrations of metals than adults (Lindqvist 1992; Diener et al. 2015).

Studies on the feed safety of farmed insects are very limited. Charlton et al. (2015) investigated a variety of insect species cultivated in several geographical locations, using different rearing substrates and conditions. The heavy metals cadmium, lead, mercury and the metalloid arsenic were found in larvae of MD, Blue bottle (*Calliphora vomitoria*), Blow fly (*Chrysomya spp.*) and HI. The EU maximum allowed levels for cadmium, lead, mercury and arsenic in complete fish feed and feed materials are set at 0.5, 5, 0.1, 2 and 2, 10, 0.1, 2 mg/kg (88% dry matter), respectively (EU 2002). The concentrations of these undesirables in the fly larvae analysed by Charlton et al. (2015) were all below the maximum limits.

During rearing, insects could accumulate contaminants present in their feeding media. However, only few studies have investigated the influence of different feeding substrates on metal accumulation in insect larvae (Biancarosa et al. under revision; Diener et al. 2015; Vijver et al. 2003). HI larvae accumulate heavy metals when these are present in the diet, and a direct correlation exists between dietary and larval metal concentrations. This was shown using either feeding substrates spiked with heavy metals (cadmium, lead or zinc) (Diener et al. 2015) or media naturally containing these undesirable elements such as seaweeds (Biancarosa et al. under revision). Rearing insect larvae on substrates containing marine materials (seaweeds, tunicates, FM) resulted in the uptake of cadmium, lead, mercury and arsenic also in TM and super worms (Biancarosa et al. unpublished results). Vijver et al. (2003) previously documented accumulation of cadmium and lead in mealworms, when fed on soils contaminated with these contaminants.

The transfer of heavy metals and arsenic from feeding substrates to insect larvae highlights the need to carefully choose the material that is used to rear the larvae. However, there are currently big knowledge gaps related to the influence of different substrates on the metal content of farmed insects, thus further studies are required. Moreover, besides exploring the metal content of non-processed insects (e.g. whole larvae), documentation of the occurrence of these undesirable elements in processed larvae products (e.g. IM and insect lipid (IL)). Processing of the insect raw materials could potentially reduce metal contaminations prior to feeding. Further research is also needed to investigate whether heavy metals (or other potential risks) present in insects used for feed, are transferred to farmed fish.

Other chemical hazards may be present in rearing substrates for insects, thus may end up in insects and products thereof. In respect of the EU feed legislation (EC Directive 2002/32 and amendments) (EU 2002), Charlton et al. (2015) investigated the presence of dioxins, PCBs, polyaromatic hydrocarbons (PAHs), pesticide residues, veterinary drugs and mycotoxins in farmed insects destined to animal feed (house fly, blue bottle, blow fly and black soldier fly). These contaminants were found in the insect species tested, although in concentrations generally below current regulatory limits for these compounds in animal feed. Only the veterinary medicine nicarbazin (4,4′-dinitrocarbanilide) was detected at concentrations above the maximum allowed in animal feed (500 μg/kg) in one sample of MD due to the use of contaminated animal manure as growth medium for the larvae. Risks of this kind are minor in the EU, where feeding manure to farmed insects is currently prohibited. However, outside the EU other regulations apply. Insect meals produced outside the EU can be imported however they have to fulfil the same requirements set by the abovementioned EC Directive when used in feeds. For some of the compounds detected by Charlton et al. (2015) (e.g. PAHs and the pesticide residue chlorphyrifos), no maximum limits are currently established for animal feed.

Microbiological hazards related to the use of insects for feed purposes have been taken into account in the first "Risk profile related to the production and consumption of insects as food and feed" by EFSA (2009). Like other famed animals, microorganisms can be naturally associated with insects (e.g. the microbiota in the guts or on the surface), or can be introduced during rearing processes. However, very little studies on the microbiological safety of insects for food and feed are currently available (Klunder et al. 2012) to support such risk analysis.

4 Conclusion

Studies on IM inclusion in aquafeeds so far have focussed on FM replacement and growth performance, which is a logical first step for any new feed ingredient. Other aspects (both positive and negative) of IM on fish health are expected to be addressed over time, e.g. intestinal health, changes in microbiota, immunology, etc. There is also clearly an important role for insect processing (de-fattening, protein isolation, hydrolysation, etc), which can affect the properties of a meal into a great extent. The effect of chitin is still under investigation, and no conclusive evidence exists of chitin functioning as an anti-nutrient, immunostimulant, or any other function that has been proposed. Moreover, the role of the substrate on the quality of the meal is of a major importance as both the nutrient composition and content of undesirables are (partly) dictated by the composition of the insect feeding substrate. The approval of the EU Commission of the use of insect PAP in aquafeeds on the 13th December 2016 most likely triggers a surge in both demand and supply of IM and exiting developments in this field of research are expected. Signals from feed producers indicate a strong interest in using this resource if volumes are reaching 40.000 MT or more and the price is competitive. The increase in IM demand will inevitably lead to a decrease in IM selling price that is until now, still not competitive if compared with other protein sources commonly used in aquaculture feeds. Finally, initial studies on consumer acceptance of insect-fed fish showed a positive consumer attitude (Verbeke et al. 2015; Mancuso et al. 2016), but additional studies will be needed when insect products will reach the market.

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