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DO INSECTS AS FEED INGREDIENT AFFECT MEAT QUALITY?

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Abstract
The development of sustainable feed ingredients for monogastric livestock is nowadays considering insect meals and oils to replace or supplement conventional feedstuffs. Although the regulation on the use of insect products differs among countries resulting in restrictions on use in the diets of monogastric meat producers, global research is exploring all the strengths and weaknesses of their inclusion. Therefore, whereas the scientific literature has extensively studied both the relationship between insect farming systems and safety (potential health risks), and between the dietary use of insects and the nutritional value of diets and production performance of farm animals (fish, poultry, swine, rabbit), the relationship between insect-containing diet and meat quality has only recently been considered. The present review therefore aims to collect the results of the studies that have related the dietary use of some insect species, such as the black soldier fly (Hermetia illucens), the yellow mealworm (Tenebrio molitor) and the silkworm (Bombyx mori), on the physicochemical and sensory traits of the poultry, swine and rabbit meat. The variable that has been most affected by the inclusion of insects as feed on livestock meat quality is the fatty acid (FA) profile, which, as is well known, in monogastrics tends to reflect that of the diet. Therefore, the black soldier fly inclusion has always originated meats with a more saturated FA profile, the yellow mealworm a more monounsaturated fatty acid profile, whereas the silkworm a more unsaturated fatty acid profile and rich of valuable omega-3 FA, but rarely changed the related physicochemical variables, or the sensory profile of the meat.

Introduction

Statistics about demographic trends depict that by 2050 the World's population should reach 9.1 billion people. This scenario is putting pressure on the search for alternative and sustainable feed resources for the livestock sector. This was officially emphasised by the Food and Agriculture Organisation (FAO) of the United Nation in Report "The future of food and agriculture — Alternative pathways to 2050" [1]. Among the possible alternative feed (and food) sources, insects are seen as one of the most effective alternatives to improve global food and feed security, with remarkable potential sustainability [2]. In fact, insects generally reproduce quickly, have fast growth and high feed conversion efficiency, and can be reared on a wide range of bio-waste streams, thus becoming an effective natural tool to recycle waste into nutritionally rich feed/food ingredients. Compared with traditional protein production, that of insect has a really low hydric and ecological footprint, and its production requires small lands to be exploited for very high yield [3].

Why insects in animals' diet?

In addition to the above reasons, the use of insects in animal feeding is supported by the fact that numerous animal species among birds and mammals consume insects as part of their natural diet. About 80% of birds are reported to include insects in their diets [4], among which there are also the chicken (*Gallus gallus*), the turkey (*Meleagris gallopavo*), the guinea fowl (*Numida meleagris*), the quail (*Coturnix coturnix*), and the ostrich (*Struthio camelus*), which are species of interest for food production in different Regions of the World [5–8].

Fish also eagerly consume insects in nature: both terrestrial and aquatic insects are considered part of the natural diet of both freshwater (black carp (*Mylopharyngodon piceus*), African catfish (*Clarias gariepinus*), common catfish (*Ameiurus melas*) [9,10]) and marine fish (chum salmon (*Oncorhynchus keta*), Atlantic salmon (*Salmo salar*) [11,12]).

There are also some mammal species (such as the wild boar) that have a varied diets, in which insects are a part of them. Among the monogastric mammals used as a food source in many Countries, there is the farmed rabbit, which naturally does not include insects in its diet, but the lipid source generally consisting of sunflower oil and soybean oil could be partially replaced with insect oil, as alternative and sustainable feed resource.

Insects as feed ingredient

In 2014 the first international conference on "Insects to feed the world" was organized by the FAO [13] which proposed, from the first time, the use of insects as promising alternative food and feed sources as a possible solution related to the expected demographic growth. Since that time, a new research field has emerged and an impressive number of articles have been published (see reviews of [14–29]), with an exponential increase in scientific knowledge on insects as feed.

Most studies have focused on the potential industrial application of certain insect species and have shown that

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black soldier fly (*Hermetia illucens*) and yellow mealworm (*Tenebrio molitor*) have great potential in providing large-scale and high-quality nutrients for aquaculture, poultry and pig diets, exploiting bio-waste and organic side-streams [30].

In parallel, an increasing number of research is testing the feed use of insects by focusing on the circular economy of small and medium-sized livestock farm, with the aim of making them independent from the global market, thus differently sustainable, or focusing on niche products such as meat from native breeds to preserve the biodiversity, or raised according to the organic system [29].

Regulation

Geographically, there are three main legislative scenarios: 1) the Anglo-Saxon countries (Australia, Canada, New Zealand, UK, USA), for whom insects are not treated as unique/novel food and feed, and therefore the food and feed agencies have generally approved import and sales upon fulfilment of certain quality and safety requirements; 2) the Asian, centre- and south-American, and African countries, for which insects are usually considered a conventional food and feed; 3) the European Union, for which it is necessary to establish rules and supply approval before permitting any trade of a specific food/feed product.

The result from these extremely diversified scenarios, is that also the legislation structure of different areas around the World regarding insects' use as food and feed is extremely heterogeneous. To respond to the new food and feed trends worldwide, and thus market exigencies and perspectives, the legislative frameworks of countries are rapidly changing.

In the European Union (EU), there is no history related to possible use of insects as food. In 2015, the European Parliament established that insects could fall into the "novel foods" category, and consequently they are subject to the consequent approval processes. Recently, EFSA [31] approved the yellow mealworm as a novel food, and the European Commission is discussing a regulation authorising this insect as a food.

Likewise, there is no history in the EU regarding the use of insects as feed application. Only in 2014 the FAO conference triggered a gradual change in the EU legislative framework, which is still evolving. Currently, processed animal proteins (PAPs) extracted from insects are allowed to be used in aquaculture, laboratory, companion and fur animals (regulation (EU) no. 2017/893), whereas for poultry species and pigs discussion is still going on, thus legislation still needs to be updated. Conversely, the fat fraction extracted from insects is allowed as feed ingredient for any animal species. The regulation allows the use of seven insect species: the black soldier fly (*Hermetia illucens*), the yellow mealworm (*Tenebrio molitor*), the lesser mealworm (*Alphitobius diaperinus*), the house cricket (*Acheta domesticus*), the field cricket (*Gryllus assimilis*), the banded cricket (*Gryllodes sigillatus*), and the common house fly (*Musca domestica*), specifying also the substrates allowed to feed insects. Regulation (EU) 2017/1017 permits the use of live or dead terrestrial invertebrates with or without treatment as feed material, but not as processed as described in Regulation (EC) no. 106/2009. Thus, invertebrates are considered as a suitable material for a feed at all the stages of their lives, except for species that adversely affect plants, animal, or human health.

Within the EU, however, starting from the above-mentioned common legislative framework every country has adopted this legislative framework differently. As an example, Belgium, The Netherlands, Great Britain, Denmark and Finland, refer to national laws which allow the production, marketing and trade of insect-based products. Instead, Germany show a limited degree of tolerance, whereas other states (i. e., Italy), have close to zero tolerance.

Recently (on May 25 2021), delegates of the EU-27 in the EU Standing Committee on Plants, Animals, Food and Feed (PAFF Committee) backed draft regulation aimed at setting EU harmonised standards for insect frass and the addition of silkworm to the list of seven approved insect species for use as protein in aquaculture feed [32]. The silkworm species was already approved for use in the feed of non-food producing animals, and was evaluated by the EFSA in its insect protein risk profile opinion in 2015. On 22 June 2021 the ENVI (Committee on the Environment, Public Health and Food Safety of the European Parliament) backed the draft Commission Regulation amending Annex IV to Regulation (EC) No 999/2001 which would remove the ban on the use of PAPs (including insect-derived protein) in poultry and pig feed, which was approved by the European Commission on 17 August 2021, and it will enter into force on the twentieth day following that of its publication in the Official Journal of the European Union [32].

Insect nutritional sources and formulation

To exploit the maximum potential as feed ingredient, insects are processed to obtain whole insect meal (full-fat), protein meal (PAPs; only for aquaculture, pet and fur animals) which can be defatted or contain some proportion of lipids according to the extraction method, and fat/oil (for all animal species). In addition, there are also bioactive compounds, such as the chitin [33], the 1-deoxynojirimycin (1-DNJ, [34]), and the lauric acid [35] that can be extracted from insects and used for different industrial applications.

The high variability of the nutritional composition of insect species can be an issue when focusing on its use as feed ingredient. In particular, the quantity and quality of insect lipids play a leading role, since their nutritional contribution varies primarily according to the insect species, their living substrate and growth stage, and then, according to the degree of lipid extraction of the insect meal [2]. Therefore, the use of defatted insect meal ensures a more constant feed formulation.

The extracted insect fat/oil can serve as feed ingredient alternative to fish and other vegetable oils, but also as food ingredient, in the cosmetic industry and as biofuel. The fatty acid (FA) profile of insects lipids can be very extreme: two examples are the *Hermetia illucens* and the *Bombyx mori*. The fat extracted from *Hermetia illucens* larvae contains 60–79% SFA. Conversely, the *Bombyx mori* chrysalis is very rich in omega-3 PUFA [36] and its oil presents a favourable n-6/n-3 ratio of 0.17 (personal communication). Thus, combining full-fat or partially defatted insect meal from different species could help ensure the best FA profile for animal feed [3]. The amino acid profile also differs between the different species of insects; in the case of the *Tenebrio molitor* larva the content of all individual amino acids was found to be higher than that of barley, fish, brewer's yeast, beef/veal, and crustaceans, except for lysine, which was slightly higher in brewer's yeast [31].

Research studies conducted so far have tested a wide range of levels of substitution (5–100%, mainly with fishmeal or soybean meal) or inclusion (0.75–60%) of insect meal, to find the best level, to cover nutrient requirements and to maximise growth and health performance, and product quality from farmed aquatic and terrestrial animals (see review of [17]). Pioneering research is also testing the effect of feeding live larva on poultry, but has so far only focused on improving animal welfare [37] or laying hen egg production and quality [38].

Insects in feeds and meat quality

The effects of dietary insect products (larva meal, prepupa meal, oil) inclusion on the quality of food-producing terrestrial animals have been studied mainly in poultry, with sporadic and recent interest in porcine and rabbit species. The purpose of this review is to provide updated literature on the use of insect-based products as feed for meat-producing animals, detailing the effects on the physico-chemical-sensory quality of the meat obtained. The review will consider the black soldier fly (*Hermetia illucens*), the yellow mealworm (*Tenebrio molitor*), and the silkworm (*Bombyx mori*), the first two for the greatest commercial interest in the EU, the third because it is potentially interesting in improving the dietary-nutritional value of meat. To be used as feed compounds, insect products can be used partially processed (dried larva) or processed (partially or totally defatted meals, dechitinised meals, fats/oils). The use of live larva in livestock feed is in its infancy and currently poses some technical limitations. Regarding the inclusion/substitution level of insects and insect-derived products in feed, a wide range has been tested, and for each insect species the best inclusion/substitution range is being identified.

Dietary inclusion of black soldier fly (Hermetia illucens) and meat quality

The black soldier fly larva is one of the most used organism for aquaculture and one of the best studied for both aquaculture and poultry feeding. The black soldier fly larva averagely contains 43.1±5.05 g protein /100 g DM, and the amino acid profile is rich in leucine (6.72 g/100 g protein), lysine (6.22±1.08 g/100 g protein), and valine (5.38±0.82 g/100 g protein). Nutritionally important is also its contribution in calcium (24.1±12.8 g/kg DM) and phosphorus (6.01±1.77 g/kg DM) (see review of [29]). As aforementioned, the amount of larva fat and its FA profile are extremely variable and depend on the type of substrate. A description of the results obtained on the meat quality of poultry, pigs and rabbits is provided below.

Poultry

Based on numerous studies (Table 1), the black soldier fly as meal or fat in poultry diets has no [39–48] or limited influence [41,42,47–50] on physical meat quality (pH, colour, water holding capacity (WHC), shear force) of broiler's chicken, quail, barbary partridge, and muscovy duck. Similarly, the poultry meat proximate composition also showed alternate results, and they do not seem related to the insect meal inclusion level. Differences in meat nutrients composition were mainly observed for more protein content [42,50], for lowered [45] or increased [43,51] essential amino acids, and for enrichment in minerals, like calcium [51], sulfur [49], and cupper [40]. In general, the sensory evaluation of poultry meat derived from animals fed diets supplemented with black soldier flies did not differ from that obtained from control diets [41,44,51]. Instead, the black soldier fly inclusion as meal or fat had a major contribution in modifying the FA profile of the lipids in the poultry meat [40–43,45,47,50–54].

Considering that the FA profile of the meat of monogastric animals is in line with the pattern of that of their diet, and that the black soldier fly (whatever its form) is rich in saturated fatty acids (SFA; approximately 70% of the total FAME, of which 43% is represented by the C12:0 [48] it follows that the proportion of SFA in meat increases as a function of the dietary inclusion level of the black soldier fly. In majority of the cases, this implies a worsening of the n-6/n-3 ratio [43], but either insect defatting or their food substrate, may not change [49] or improve [45] the omega-6/omega-3 ratio.

If the FA profile of the meat is changed by the inclusion of the black soldier fly in the poultry diet, changes in the lipid oxidation of the meat is also expected. However, most of the studies did not observe changes in the oxidation of meat lipids in animals fed black soldier fly [40,51,53]. However it is interesting to note that Choi et al. [39] observed a significantly low TBARS value on fresh meat after 7 days of refrigerated storage, and authors attributed it to the improved antioxidant activity (measured through the DPPH radical scavenging activity) of the meat due to the inclusion of the black soldier fly in the diet.

Table 1. Effect of dietary inclusion of black soldier fly on broiler meat quality.

Item	Avian species	Insect form	Substitution level range (%)	Inclusion level range (%)	Impact	References
pH, cooking loss[1], shear force[1]	chicken	meal	50–75	0.5–1.0 5–15	NS NS NS	[39] [1][41] [42]
Colour[1; 2], TBARS[a], DPPH radical scavenging	chicken	meal	25–50	0.5–1.0 5–15	P < 0.05 P < 0.05 P < 0.05	[39] [1][49] [2][42]
pH[1; 2], colour[1; 2], lipid oxidation, cooking loss, shear force	chicken	meal	 50–75	5–20 5 	NS P < 0.05 P < 0.05	[43] [1][50] [2][41]
Amino acid, FA[b] profiles	chicken	meal		5–20	P < 0.05	[43]
FA profile	chicken	meal	25–50 50–75 	 5 5–15	NS P < 0.05 P < 0.05 P < 0.05	[49] [50] [41] [42]
Mineral profile	chicken	meal	25–50		P < 0.05	[49]
Bioactive peptides, volatile profile	chicken	meal	100		P < 0.05	[55] [56]
Proximate composition	chicken	meal	50–75	5 5–15	P < 0.05 NS P < 0.05	[50] [41] [42]
Sensory evaluation	chicken	meal	50–75		NS	[41]
pH, colour, WHC[c], proximate composition, amino acid, FA and mineral profiles, sensory evaluation	chicken	meal		5–15	NS	[44]
FA profile	chicken	fat	100 50–100 50–100		P < 0.05 P < 0.05 P < 0.05	[52] [53] [54]
pH[1], thaw loss, proximate composition[1], TBARS	chicken	fat	50–100		NS NS	[53] [1][54]
Cholesterol	chicken	fat	50–100		P < 0.05/NS	[53]
Sensory evaluation	chicken	fat	50–100		NS	[53]
pH, colour, total moisture loss, shear force, heme iron, shelf life	quail	meal		10	NS	[45]
Proximate composition, cholesterol, amino acid, FA profiles, sensory evaluation	quail	meal		10	P < 0.05	[45]
pH, colour, WHC, shear force	quail	meal	25–100		NS	[46]
Proximate composition, sensory evaluation, cholesterol, TBARS	quail	meal		10–15	NS	[51]
Mineral, FA, amino acid profiles	quail	meal		10–15	P < 0.05	[51]
pH, cooking loss	quail	meal		10–15	P < 0.05	[48]
Colour, shear force, amino acid profile	quail	meal		10–15	NS	[48]
pH, shear force, cook loss, proximate composition	barbary partridge	meal	25–50		NS	[47]
Colour, FA profile	barbary partridge	meal	25–50		P < 0.05	[47]
pH, colour, proximate composition, TBARS	muscovy duck	meal		3–9	NS	[40]
FA profile, mineral profile	muscovy duck	meal		3–9	P < 0.05	[40]

[a]TBARS = Thiobarbituric acid reactive substances; [b]FA = fatty acids; [c]WHC = water holding capacity

Pig

The results until now obtained on feeding pigs with inclusion of black soldier fly meal highlighted any influence on the tested physical meat quality (pH, colour WHC, shear force; Table 2) [57,58]. As regards the meat proximate composition, Altmann et al. [57] did not observe differences, whereas a more recent study of Chia et al. [59] found higher protein content in groups fed with black soldier fly meal, but not in that with the highest substitution level.

The meat from pigs fed black soldier fly meal had higher concentrations of K, Fe and Zn [59], thus providing additional functional and nutritional minerals for humans. The dietary inclusion of 4% black soldier fly meal increased the marbling score of the *Longissimus thoracis* muscle, and upregulated the expression of genes related to lipid metabolism and to myosin heavy chain (MyHC–IIa) isoform, likely inducing the muscle fibre transition towards more oxidative fibres [58]; however the effect was not observed at the 8% inclusion level, and therefore further research should be provided to support this finding.

As expected, the lipids FA profile of the pork meat was affected by the dietary inclusion of black soldier fly meal, but to a lesser extent than in poultry. In fact, even if some single FA significantly differed (C12:0, C14:0, C16:1, C18:3 n-3, C20:4 n-6, C20:5 n-3, C22:6 n-3), no difference in FA classes or in n-6/n-3 ratio was observed [58]. The only sensory evaluation conducted so far, which considered 26 attributes, revealed statistically significant differences only in odour intensity and juiciness with the inclusion of insect meal in the diet, both considered as sensory improvements [57].

The exiguous number of research conducted until now on the use of black soldier fly meal in pig diets does not allow a detailed assessment of their effect on meat quality, but the response appears to be slightly more subdued than that observed in poultry, with positive implications especially in terms of FA profile.

Rabbit

For rabbit diets, the studies so far conducted only considered the fat obtained from the defatting of the black soldier fly meal (Table 3). Dalle Zotte et al. [60] evaluated the total replacement of the dietary fat source: linseed oil vs black soldier fly fat at 2 inclusion levels (3% and 6%), whereas [61] the partial (50%) or total replacement of soybean oil with black soldier fly fat.

The first study highlighted differences in rabbit meat colour (increased redness) and in oxidative stability (lower TBARS), whereas the second one did not find difference in meat physical traits, proximate composition and sensory evaluation. Both studies obtained the same response in terms of TBARS values, and similar response for the FA profile, that is oriented towards higher saturated FA proportion (C12:0 and C14:0).

These two studies provided new insights into the use of black soldier fly fat in rabbit diets, considering it an excellent substitute for commonly used oils and fats.

*Dietary inclusion of yellow mealworm (**Tenebrio molitor**) and meat quality*

The yellow mealworm larva is gaining attention as a source of protein for food purposes worldwide, and, recently, the EU included it in the Union list of authorised novel foods [62]. Yellow mealworm is also considered

Table 2. Effect of dietary inclusion of black soldier fly on pork meat quality

Item	Feeding length	Insect form	Substitution level range (%)	Inclusion level range (%)	Impact	References
Proximate composition, mineral profile	98 days	meal	25–100	6–14	P < 0.05	[59]
pH, colour, drip loss, shear force	46 days	meal		4–8	NS	[58]
Marbling score, IMF, IMP, mRNA expression to lipid metabolism and MyHC, FA profile	46 days	meal		4–8	P < 0.05	[58]
pH, colour, cooking loss, shear force, proximate composition, TBARS[a]	25–110 kg LW	meal	50–100		NS	[57]
Sensory evaluation	25–110 kg LW	meal	50–100		P < 0.05	[57]

[a]TBARS=Thiobarbituric acid reactive substances

Table 3. Effect of dietary inclusion of black soldier fly on rabbit meat quality

Item	Insect form	Substitution level range (%)	Inclusion level range (%)	Impact	References
Colour, TBARS[a], FA[b] profile	fat	100 (linseed *vs* BSF)	3–6	P < 0.05	[60]
pH, colour, WHC[c], shear force, proximate composition, sensory evaluation	fat	50–100		NS	[61]
FA profile, TBARS	fat	50–100		P < 0.05	[61]

[a]TBARS=Thiobarbituric acid reactive substances; [b]FA= fatty acids; [c]WHC=water holding capacity

a nutritionally suitable substitute for fishmeal and soybean for aquaculture and poultry diets, although its cost is currently too high and cannot financially compete with standard feed sources. It should be emphasised that the strength of this feedstuff therefore lies in the high protein content (Nx6.25: 56–61%), characterised by a high biological value, as it includes all the essential amino acids, in favourable proportions. Furthermore, it is a rich source of phosphorus [29] and potassium [31]. Fat (25–30%) contains approximately 24% saturated FA and polyunsaturated FA, and 50% monounsaturated FA, resulting in an omega-6/omega-3 ratio of 24 [31].

Poultry

Contrasting results were obtained for physicochemical traits of meat from chicken broilers, apparently not depending on the inclusion level of yellow mealworm meal (Table 4). However, the majority of the studies did not observe change in the meat pH, colour, moisture loss, shear force, and fatty acid profile [63–65]. Instead, [66] observed that the variables considered (WHC, lipids, ash, TVB-N, and sensory attributes) worsened as the level of yellow mealworm in the diet increased, and the authors partly attributed this trend to the possible presence of oxidised fat in dried insect meal. On the other hand, no other studies, testing higher yellow mealworm inclusion levels, found adverse effects on sensory traits; on the contrary, [67] observed an improvement in meat juiciness and tenderness. When other poultry species were considered, such as Barbary partridge [47] and quail [68], no substantial differences in the meat physicochemical traits were observed due to the use of moderate to high levels of yellow mealworm in the diet. Only meat colour changed in both bird species, however with an unclear pattern, whereas the FA profile of the barbary partridge meat was significantly affected by the dietary yellow mealworm, particularly at the higher substitution level (50% of the soybean meal) [47]. FA changes resulted in the reduction of the C18:0 and omega-6/omega-3 ratio ($P<0.05$) and the increase of C14:0, C15:0, C16:1, and C18:1.

Pig

Only one research has considered the use of yellow mealworm meal as dietary protein source in growing pigs [69] (Table 5). Authors tested the hypothesis that partial or complete replacement of a conventional protein source by yellow mealworm larva meal can influence the intermediary metabolism of the pig.

The omics-techniques on key metabolic tissues (liver, muscle and plasma) demonstrated that the insect meal from yellow mealworm can be used as a dietary source of protein in pigs without strongly impairing their metabolism, and consequently their growth performance. In addition, the unaltered plasma and liver triglycerides and cholesterol concentrations rather indicated that the insect meal had no effect on lipid metabolism in pigs. Studies in this regard are in their infancy, and further research is desirable to evaluate pros and cons, in order to provide precise information on the possibility of using yellow mealworm meal in pig feeding.

Table 4. Effect of dietary inclusion of mealworm on broiler meat quality

Item	Avian species	Insect form	Substitution level range (%)	Inclusion level range (%)	Impact	References
Proximate composition, sensory evaluation	chicken	meal		17	NS	[63]
pH, colour, WHC[a], proximate composition, TVBN[b], sensory evaluation	chicken	meal		1–3	P < 0.05	[66]
pH, colour, drip loss, proximate composition, FA[c] profile	chicken	meal		7.5	NS	[64]
pH, colour, WHC, shear force	chicken	meal		2–8	NS	[65]
Sensory evaluation	chicken	meal		8.1	P < 0.05	[67]
pH, shear force, cook loss, proximate composition, cholesterol	barbary partridge	meal	25–50		NS	[47]
Colour, FA profile	barbary partridge	meal	25–50		P < 0.05	[47]
WHC	quail	meal		7.5–30	NS	[68]
Colour	quail	meal		7.5–30	P < 0.05	[68]

[a]WHC=water holding capacity; [b]TVBN=Total volatile basic nitrogen; [c]FA= fatty acids

Table 5. Effect of dietary inclusion of mealworm on pork meat quality

Item	Feeding length	Insect form	Substitution level range (%)	Inclusion level range (%)	Impact	References
transcriptome, lipidome and metabolome of liver and muscle	4 week	meal		5–10	NS	[69]

Rabbit

The dietary inclusion of 4% yellow mealworm meal did not modify the proximate composition of the rabbit meat (Table 6). The amino acids content was modified by the dietary inclusion of insect meal, but the pattern observed in the 2 meat portions (hind leg and saddle) was not unidirectional, suggesting going deeper into the study of this effect. Notably, phenylalanine and lysine significantly decreased in hindleg meat, whereas threonine, isoleucine and methionine significantly increased, and tryptophan decreased in saddle meat [70]. In the same study, the authors observed that the effect of the dietary inclusion of 4% yellow mealworm on the FA profile of rabbit meat was negligible, leading only to an increase in total MUFA (from 22.0 to 22.9% total FAME, for control and treated groups, respectively; P<0.05) due to the increase in C12:0, and a decrease in EPA and DHA (P<0.05); The other FA classes and the omega-6/omega-3 ratio remained unchanged.

Based on these first results, despite being derived from a single study, it appears that a low inclusion level of dried mealworm larva in the rabbit diet does not appear to have adverse effects on meat quality. However, future studies are needed to consolidate the results obtained so far.

*Dietary inclusion of silkworm (**Bombyx mori**) and meat quality*

The silkworm pupa is characterised by high protein content (53.9% in the full-fat meal, 66.7% in the defatted meal), by a variable amount of lipids (29% in the full-fat meal, 9.5% in the defatted meal), the latter able to provide an extremely healthy FA profile (omega-3 FA: 29.5% in the full-fat, and 31.5% total FAME in the defatted meal), suggesting that it is a valuable nutritional ingredient for feed of different monogastric livestock species [36].

Poultry

Silkworm pupa meal has been successfully included in chicken broilers diet (Table 7), as it produced no effect neither on colour values and lipids content [71] nor on sensory analysis [63] [67] of the meat. A slight effect has been observed for lipids (3.56 vs 4.48% for leg meat of control and treated, respectively) in the study of [63] and for protein and ash contents (however not coherent with the inclusion level; [71]). Meat pH increased with the silkworm meal inclusion level but it did not impair meat colour [71].

The best result of the dietary inclusion of silkworm pupa meal in chickens concerns the FA profile of the meat lipids: the PUFA n-3 increased, and the omega-6/omega-3 ratio decreased with the increase of the dietary silkworm meal substitution level (P<0.01). The C18:3 n-3 content in breast meat ranged from 6.75 to 15.0 to 28.4 mg/100 g meat, for control, 25% and 50% silkworm meal inclusion level, respectively (P<0.05; [71]).

Rabbit

The silkworm pupa has been tested on rabbits diet in two forms: meal [70,72] and oil [73,74] (Table 8). Meat proximate composition was not modified by the silkworm pupa products [70,72,74] as well as the meat physicochem-

Table 6. Effect of dietary inclusion of mealworm on rabbit meat quality

Item	Insect form	Inclusion level (%)	Impact	References
Proximate composition	meal	4	NS	[70]
FA[a] profile, amino acid profile	meal	4	P < 0.05	[70]

Table 7. Effect of dietary inclusion of silkworm on broiler meat quality

Item	Avian species	Insect form	Substitution level range (%)	Inclusion level range (%)	Impact	References
Proximate composition, sensory evaluation	chicken	meal		17	NS	[63]
Colour	chicken	meal	25–50	7–14	NS	[71]
pH, proximate composition, FA[a] profile	chicken	meal	25–50	7–14	P < 0.05	[71]
Sensory evaluation	chicken	meal		7.8	NS	[67]

[a]FA= fatty acids

Table 8. Effect of dietary inclusion of silkworm on rabbit meat quality

Item	Insect form	Substitution level range (%)	Inclusion level range (%)	Impact	References
Proximate composition	meal		4	NS	[70]
FA[a] profile, amino acid profile	meal		4	P < 0.05	[70]
Proximate composition	meal	50–100	5–10	NS	[72]
FA profile	meal	50–100	5–10	P < 0.05	[72]
pH, WHC[b], proximate composition, sensory evaluation, TBARS[c]	oil	100	1.30	NS	[74]
FA profile	oil	100	1.30	P < 0.05	[73]

[a]FA = fatty acids; [b]WHC = water holding capacity; [c]TBARS = Thiobarbituric acid reactive substances

ical traits (pH, WHC), oxidative status (TBARS), and sensory traits [74].

The amino acid profile slightly changed with the silkworm pupa meal inclusion in the rabbit diet: tryptophan increased and lysine decreased ($P<0.05$) in hind leg meat, whereas isoleucine increased ($P<0.05$) in saddle meat [70]. Also the cholesterol content significantly decreased in both meat cuts of animals fed the silkworm pupa meal, thus reducing the already low level of cholesterol in the rabbit meat [70].

Similarly to what observed for the poultry meat, the greatest effect of the use of silkworm pupa products is on the FA acid profile of the rabbit meat obtained.

The 5 and 10% inclusion level of silkworm meal considerably increased the levels of C18:3 n-3, C22:5 n-3 and C22–6 n-3 in hind leg meat [72], but a lower inclusion level (4%) obtained similar results for omega-3 FA, and favourably reduced the omega-6/omega-3 ratio of the same meat portion (ratio of 4.5, compared to that of 7.8 of the control group; $P<0.01$ [70]. The 100% substitution of sunflower oil with silkworm pupa oil significantly ($P<0.01$) lowered n-6 FA and increased n-3 FA, resulting in a omega-6/omega-3 ratio of 7.7 (compared to that of 18.9 of the control group) in hind leg [73].

Conclusion

The great economic impulse towards the use of insects as food and feed for the ecological-environmental sustainability purpose has generated new companies producing insect meal and derivatives. A flywheel of interest has therefore been generated on several fronts, and the use of these products increasingly requires confirmation of safety and efficacy. In the last 5 years, numerous research has been conducted relating to the use of insects for alimentary use. Many of these aimed at the feed sector, which however has mainly considered the effect of their use on animal *ante-mortem* variables, whereas the study of the effects on nutritional, rheological and sensory quality of the meat has only intensified significantly in the last 2 years. This review focused on collecting and describing the results of research conducted so far on the effect of insects as feed on the meat quality of terrestrial monogastric animals. The results showed different effects, more of these depending on the insect species than on the animal species that benefited from them. Overall, no adverse effects were observed on meat quality. Only the meat's FA profile was affected by the insect species included in the diet, suggesting its improvement through manipulation of the insect substrate, or the use of mixtures of insect meal or oil from different insect species.

REFERENCES

1. FAO (2018). The future of food and agriculture — Alternative pathways to 2050. Rome, 2018. 224 pp.
2. van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G. et al. (2013). Edible insects: future prospects for food and feed security (No. 171). Food and Agriculture Organization of the United Nations. Retrieved from https://edepot.wur.nl/258042 Accessed May 25, 2021
3. Makkar, H. P. S., Tran, G., Heuzé, V., Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, 197, 1–33. https://doi.org/10.1016/j.anifeedsci.2014.07.008
4. Mwansat, G. S., Turshak, L. G., Okolie, M. O. (2015). Insects as important delicacy for birds: expanding our knowledge of insect food ecology of birds in the tropics. *Journal of International Scientific Publications: Ecology & Safety*, 9, 434–441.
5. FAO (2013) Edible insects: future prospects for food and feed security. FAO Forestry Paper 171. Rome, 2013.
6. Badenhorst, A., Kerley, G. I. H. (1996). Seasonal variation in the diet of common quail coturnix coturnix in the Eastern Cape. *South African Journal of Zoology,* 31(3), 159–161. https://doi.org/10.1080/02541858.1996.11448408
7. Witt, A. R., Little, R. M., Crowe, T. M. (1995). The effectiveness of helmeted guineafowl numida meleagris (Linnaeus 1766) in controlling the banded fruit weevil phlyctinus callosus (schönherr 1826), and their impact on other invertebrates in apple orchards in the Western Cape province, South Africa. *Agriculture, Ecosystems and Environment*, 55(3), 169–179. https://doi.org/10.1016/0167–8809(95)00626–4
8. Yassin, O. E., Gibril, S., Hassan, A. H. A., Bushara, B. A. (2013). A study on Turkey (*Meleagris gallopavo*) raising in the Sudan. *Journal of Applied and Industrial Sciences*, 1(4), 11–15.
9. Nico, L. G., Williams, J. D., Jelks, H.L. (2005). Black carp: biological synopsis and risk assessment of an introduced fish. Special Publication, 32. Published by the American Fisheries Society, 2005. https://doi.org/10.47886/9781888569681
10. Burgess, W. E (1989). An atlas of freshwater and marine catfishes. A preliminary survey of the Siluriformes. TFH Publications, Neptune City, 1989.
11. Scott, W. B., Crossman, E. J. (1973). Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184. 966 p.
12. Page, L. M., Burr, B. M. (1991) A field guide to freshwater fishes of North America north of Mexico. Houghton Mifflin Company, Boston, USA.
13. FAO (2014). *Insects to feed the world.* (2014, May 14–17). 1st International Conference, Wageningen, The Netherlands.
14. Barragan-Fonseca, K. B., Dicke, M., van Loon, J. J. A. (2017). Nutritional value of the black soldier fly (Hermetia illucens L.) and its suitability as animal feed — a review. *Journal of Insects as Food and Feed,* 3(2), 105–120. https://doi.org/10.3920/JIFF2016.0055
15. Ssepuuya, G., Namulawa, V., Mbabazi, D., Mugerwa, S., Fuuna, P., Nampijja, Z. et al. (2017). Use of insects for fish and poultry compound feed in sub-Saharan Africa — A systematic review. *Journal of Insects as Food and Feed*, 3(4), 289–302. https://doi.org/10.3920/JIFF2017.0007
16. DiGiacomo, K., Leury, B. J. (2019). Review: Insect meal: A future source of protein feed for pigs? *Animal,* 13(12), 3022–3030. https://doi.org/10.1017/S1751731119001873
17. Gasco, L., Biasato, I., Dabbou, S., Schiavone, A., Gai, F. (2019). Animals fed insect-based diets: State-of-the-art on digestibility, performance and product quality. *Animals,* 9(4) https://doi.org/10.3390/ani9040170
18. Moula, N., Detilleux, J. (2019). A meta-analysis of the effects of insects in feed on poultry growth performances. *Animals,* 9(5), Article 201. https://doi.org/10.3390/ani9050201
19. Pinotti, L., Giromini, C., Ottoboni, M., Tretola, M., Marchis, D. (2019). Review: Insects and former foodstuffs for upgrading food waste biomasses/streams to feed ingredients for farm animals. *Animal,* 13(7), 1365–1375. https://doi.org/10.1017/S1751731118003622
20. Sogari, G., Amato, M., Biasato, I., Chiesa, S., Gasco, L. (2019). The potential role of insects as feed: A multi-perspective review. *Animals,* 9(4), Article 119. https://doi.org/10.3390/ani9040119
21. Benzertiha, A., Kierończyk, B., Rawski, M., Mikołajczak, Z., Urbański, A., Nogowski, L. at al. (2020). Insect fat in animal nutrition — A review. *Annals of Animal Science*, 20(4), 1217–1240. https://doi.org/10.2478/aoas-2020–0076
22. Chodová, D., Tůmová, E. (2020). Insects in chicken nutrition. A review. *Agronomy Research,* 18(2), 376–392. https://doi.org/10.15159/AR.20.003
23. Gasco, L., Acuti, G., Bani, P., Dalle Zotte, A., Danieli, P. P., De Angelis, A. et al. (2020). Insect and fish by-products as sustainable alternatives to conventional animal proteins in animal nutrition. *Italian Journal of Animal Science*, 19(1), 360–372. https://doi.org/10.1080/1828051X.2020.1743209

24. Hong, J., Han, T., Kim, Y. Y. (2020). Mealworm (Tenebrio molitor larvae) as an alternative protein source for monogastric animal: A review. *Animals,* 10(11), 1–20, Article 2068. https://doi.org/10.3390/ani10112068
25. Selaledi, L., Mbajiorgu, C. A., Mabelebele, M. (2020). The use of yellow mealworm (T. molitor) as alternative source of protein in poultry diets: A review. *Tropical Animal Health and Production*, 52(1), 7–16. https://doi.org/10.1007/s11250–019–02033–7
26. van Huis, A. (2020). Insects as food and feed, a new emerging agricultural sector: A review. *Journal of Insects as Food and Feed*, 6(1), 27–44. https://doi.org/10.3920/JIFF2019.0017
27. van Huis, A., Oonincx, D. G. A. B., Rojo, S., Tomberlin, J. K. (2020). Insects as feed: House fly or black soldier fly? *Journal of Insects as Food and Feed*, 6(3), 221–229. https://doi.org/10.3920/JIFF2020.X003
28. Orkusz, A. (2021). Edible insects versus meat — nutritional comparison: Knowledge of their composition is the key to good health. *Nutrients,* 13(4), Article 1207. https://doi.org/10.3390/nu13041207
29. van der Heide, M. E., Stødkilde, L., Nørgaard, J. V., Studnitz, M. (2021). The potential of locally-sourced European protein sources for organic monogastric production: A review of forage crop extracts, seaweed, starfish, mussel, and insects. *Sustainability (Switzerland*), 13(4), 1–30. https://doi.org/10.3390/su13042303
30. Veldkamp, T., Bosch, G. (2015). Insects: A protein-rich feed ingredient in pig and poultry diets. *Animal Frontiers,* 5(2), 45–50. https://doi.org/10.2527/af.2015–0019
31. Turck, D., Castenmiller, J., De Henauw, S., Hirsch-Ernst, K. I., Kearney, J., Maciuk, A. et al. (2021). Scientific Opinion on the safety of dried yellow mealworm (Tenebrio molitor larva) as a novel food pursuant to Regulation (EU) 2015/2283. *EFSA Journal*, 19(1), Article e06343. https://doi.org/10.2903/j.efsa.2021.6343
32. Commission Regulation (EU) 2021/1372 of 17 August 2021 amending Annex IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council as regards the prohibition to feed non-ruminant farmed animals, other than fur animals, with protein derived from animals.
33. Kumar, M., Vivekanand, V., Pareek, N. (2020). Insect Chitin and Chitosan: Structure, Properties, Production, and Implementation Prospective. Chapter in a book: Natural Materials and Products from Insects: Chemistry and Applications. Springer, Cham. Springer Nature Switzerland AG. https://doi.org/10.1007/978–3–030–36610–0_4
34. Yin, H., Shi, X. -Q., Sun, B., Ye, J. -J., Duan, Z. -A., Zhou, X. -L. et al. (2010). Accumulation of 1-deoxynojirimycin in silkworm, Bombyx mori L. *Journal of Zhejiang University: Science B*, 11(4), 286–291. https://doi.org/10.1631/jzus.B0900344
35. Borrelli, L., Varriale, L., Dipineto, L., Pace, A., Menna, L. F., Fioretti, A. (2021). Insect derived lauric acid as promising alternative strategy to antibiotics in the antimicrobial resistance scenario. *Frontiers in Microbiology*, 12, Article 620798. https://doi.org/10.3389/fmicb.2021.620798
36. Dalle Zotte, A., Singh, Y., Squartini, A., Stevanato, P., Cappellozza, S., Kovitvadhi, A. et al. (2021). Effect of a dietary inclusion of full-fat or defatted silkworm pupa meal on the nutrient digestibility and faecal microbiome of fattening quails. *Animal,* 15(2), Article 100112. https://doi.org/10.1016/j.animal.2020.100112
37. Veldkamp, T., van Niekerk, T. G. C. M. (2019). Live black soldier fly larvae (Hermetia illucens) for turkey poults. *Journal of Insects as Food and Feed*, 5(4), 301–311. https://doi.org/10.3920/JIFF2018.0031
38. Star, L., Arsiwalla, T., Molist, F., Leushuis, R., Dalim, M., Paul, A. (2020). Gradual provision of live black soldier fly (Hermetia illucens) larvae to older laying hens: Effect on production performance, egg quality, feather condition and behavior. *Animals,* 10(2), Article 216. https://doi.org/10.3390/ani10020216
39. Choi, S. -U., Choi, I. -H., Chung, T. -H. (2021). Investigation of breast meat traits of broilers fed different amounts of hermetia illucens and protaetia brevitarsis seulensis powder. *Entomological Research.* https://doi.org/10.1111/1748–5967.12504 (unpublished data)
40. Gariglio, M., Dabbou, S., Gai, F., Trocino, A., Xiccato, G., Holodova, M. et al. (2021). Black soldier fly larva in Muscovy duck diets: effects on duck growth, carcass property, and meat quality. *Poultry Science*. https://doi.org/10.1016/j.psj.2021.101303 (unpublished data)
41. Altmann, B. A., Wigger, R., Ciulu, M., Mörlein, D. (2020). The effect of insect or microalga alternative protein feeds on broiler meat quality. *Journal of the Science of Food and Agriculture*, 100(11), 4292–4302. https://doi.org/10.1002/jsfa.10473
42. Schiavone, A., Dabbou, S., Petracci, M., Zampiga, M., Sirri, F., Biasato, I. et al. (2019). Black soldier fly defatted meal as a dietary protein source for broiler chickens: Effects on carcass traits, breast meat quality and safety. *Animal,* 13(10), 2397–2405. https://doi.org/10.1017/S1751731119000685
43. de Souza Vilela, J., Alvarenga, T. I. R. C., Andrew, N. R., McPhee, M., Kolakshyapati, M., Hopkins, D. L. et al. (2021). Technological quality, amino acid and fatty acid profile of broiler meat enhanced by dietary inclusion of black soldier fly larvae. *Foods,* 10(2), Article 297. https://doi.org/10.3390/foods10020297
44. Pieterse, E., Erasmus, S. W., Uushona, T., Hoffman, L. C. (2019). Black soldier fly (Hermetia illucens) pre-pupae meal as a dietary protein source for broiler production ensures a tasty chicken with standard meat quality for every pot. *Journal of the Science of Food and Agriculture,* 99(2), 893–903. https://doi.org/10.1002/jsfa.9261
45. Cullere, M., Woods, M. J., van Emmenes, L., Pieterse, E., Hoffman, L. C., Dalle Zotte, A. (2019). Hermetia illucens larvae reared on different substrates in broiler quail diets: Effect on physicochemical and sensory quality of the quail meat. *Animals,* 9(8), Article 925. https://doi.org/10.3390/ani9080525
46. Mbhele, F. G. T., Mnisi, C. M., Mlambo, V. (2019). A nutritional evaluation of insect meal as a sustainable protein source for jumbo quails: Physiological and meat quality responses. *Sustainability (Switzerland),* 11(23), Article 6592. https://doi.org/10.3390/su11236592
47. Secci, G., Moniello, G., Gasco, L., Bovera, F., Parisi, G. (2018). Barbary partridge meat quality as affected by Hermetia illucens and Tenebrio molitor larva meals in feeds. *Food Research International,* 112, 291–298. https://doi.org/10.1016/j.foodres.2018.06.045
48. Cullere, M., Tasoniero, G., Giaccone, V., Miotti-Scapin, R., Claeys, E., De Smet, S., et al. (2016). Black soldier fly as dietary protein source for broiler quails: Apparent digestibility, excreta microbial load, feed choice, performance, carcass and meat traits. *Animal,* 10(12), 1923–1930. https://doi.org/10.1017/S1751731116001270
49. Kim, B., Kim, H. R., Lee, S., Baek, Y. -C., Jeong, J. Y., Bang, H. T. et al. (2021). Effects of dietary inclusion level of microwave-dried and press-defatted black soldier fly (Hermetia illucens) larvae meal on carcass traits and meat quality in broilers. *Animals,* 11(3), 1–12. https://doi.org/10.3390/ani11030665
50. Popova, T., Petkov, E., Ignatova, M. (2020). Effect of black soldier fly (Hermetia illucens) meals on the meat quality in broilers. *Agricultural and Food Science*, 29(3), 177–188. https://doi.org/10.23986/afsci.88098
51. Cullere, M., Tasoniero, G., Giaccone, V., Acuti, G., Marangon, A., Dalle Zotte, A. (2018). Black soldier fly as dietary protein source for broiler quails: Meat proximate composition, fatty acid and amino acid profile, oxidative status and sensory traits. *Animal,* 12(3), 640–647. https://doi.org/10.1017/S1751731117001860
52. Kim, Y. B., Kim, D. -H., Jeong, S. -B., Lee, J. -W., Kim, T. -H., Lee, H. -G. et al. (2020). Black soldier fly larvae oil as an alternative fat source in broiler nutrition. *Poultry Science*, 99(6), 3133–3143. https://doi.org/10.1016/j.psj.2020.01.018
53. Cullere, M., Schiavone, A., Dabbou, S., Gasco, L., Dalle Zotte, A. (2019). Meat quality and sensory traits of finisher broiler chickens fed with black soldier fly (Hermetia illucens L.) larvae fat as alternative fat source. *Animals,* 9(3), Article 140. https://doi.org/10.3390/ani9040140
54. Schiavone, A., Cullere, M., De Marco, M., Meneguz, M., Biasato, I., Bergagna, S. et al. (2017). Partial or total replacement of soybean oil by black soldier fly larvae (Hermetia illucens L.) fat in broiler diets: Effect on growth performances, feed-choice, blood traits, carcass characteristics and meat quality. *Italian Journal of Animal Science*, 16(1), 93–100. https://doi.org/10.1080/1828051X.2016.1249968
55. Gkarane, V., Ciulu, M., Altmann, B., Mörlein, D. (2020). Effect of alternative protein feeds on the content of selected endogenous bioactive and flavour-related compounds in chicken breast meat. *Foods,* 9(4), Article 392. https://doi.org/10.3390/foods9040392
56. Gkarane, V., Ciulu, M., Altmann, B. A., Schmitt, A. O., Mörlein, D. (2020). The effect of algae or insect supplementation as alternative protein sources on the volatile profile of chicken meat. *Foods,* 9(9), Article 1235. https://doi.org/10.3390/foods9091235
57. Altmann, B. A., Neumann, C., Rothstein, S., Liebert, F., Mörlein, D. (2019). Do dietary soy alternatives lead to pork quality improvements or drawbacks? A look into micro-alga and insect

protein in swine diets. *Meat Science,* 153, 26–34. https://doi.org/10.1016/j.meatsci.2019.03.001
58. Yu, M., Li, Z., Chen, W., Rong, T., Wang, G., Li, J., Ma, X. (2019). Use of Hermetia illucens larvae as a dietary protein source: Effects on growth performance, carcass traits, and meat quality in finishing pigs. *Meat Science,* 158, Article 107837. https://doi.org/10.1016/j.meatsci.2019.05.008
59. Chia, S. Y., Tanga, C. M., Osuga, I. M., Alaru, A. O., Mwangi, D. M., Githinji, M. et al. (2021) Black soldier fly larval meal in feed enhances growth performance, carcass yield and meat quality of finishing pigs. *Journal of Insects as Food and Feed*, 7(4), 433–447. https://doi.org/10.3920/JIFF2020.0072
60. Dalle Zotte, A., Cullere, M., Martins, C., Alves, S. P., Freire, J. P. B., Falcão-e-Cunha, L. et al. (2018). Incorporation of black soldier fly (Hermetia illucens L.) larvae fat or extruded linseed in diets of growing rabbits and their effects on meat quality traits including detailed fatty acid composition. *Meat Science*, 146, 50–58. https://doi.org/10.1016/j.meatsci.2018.08.002
61. Gasco, L., Dabbou, S., Gai, F., Brugiapaglia, A., Schiavone, A., Birolo, M. et al. (2019). Quality and consumer acceptance of meat from rabbits fed diets in which soybean oil is replaced with black soldier fly and yellow mealworm fats. *Animals,* 9(9), Article 629. https://doi.org/10.3390/ani9090629
62. Commission Implementing Regulation (EU) 2021/882 of 1 June 2021 authorising the placing on the market of dried *Tenebrio molitor* larva as a novel food under Regulation (EU) 2015/2283 of the European Parliament and of the Council, and amending Commission Implementing Regulation (EU) 2017/2470. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R0882&qid=1622700500774 Accessed June 16th, 2021.
63. Pietras, M., Orczewska-Dudek, S., Szczurek, W., Pieszka, M. (2021). Effect of dietary lupine seeds (Lupinus luteus L.) and different insect larvae meals as protein sources in broiler chicken diet on growth performance, carcass, and meat quality. *Livestock Science*, 250, Article 104537. https://doi.org/10.1016/j.livsci.2021.104537
64. Dabbou, S., Gasco, L., Lussiana, C., Brugiapaglia, A., Biasato, I., Renna, M. (2020). Yellow mealworm (Tenebrio molitor L.) larvae inclusion in diets for free-range chickens: Effects on meat quality and fatty acid profile. *Renewable Agriculture and Food Systems*, 35(5), 571–578. https://doi.org/10.1017/S1742170519000206
65. Elahi, U., Wang, J., Ma, Y. -B., Wu, S. -G., Wu, J., Qi, G. -H., Zhang, H. -J. (2020). Evaluation of yellow mealworm meal as a protein feedstuff in the diet of broiler chicks. *Animals,* 10(2), https://doi.org/10.3390/ani10020224
66. Shaviklo, A. R., Alizadeh-Ghamsari, A. H., Hosseini, S. A. (2021). Sensory attributes and meat quality of broiler chickens fed with mealworm (Tenebrio molitor). *Journal of Food Science and Technology.* https://doi.org/10.1007/s13197–020–04946-w
67. Khan, S., Khan, R. U., Alam, W., Sultan, A. (2018). Evaluating the nutritive profile of three insect meals and their effects to replace soya bean in broiler diet. *Journal of Animal Physiology and Animal Nutrition,* 102(2), e662-e668. https://doi.org/10.1111/jpn.12809
68. Zadeh, Z. S., Kheiri, F., Faghani, M. (2019). Use of yellow mealworm (Tenebrio molitor) as a protein source on growth performance, carcass traits, meat quality and intestinal morphology of japanese quails (Coturnix japonica). *Veterinary and Animal Science*, 8, Article 100066. https://doi.org/10.1016/j.vas.2019.100066
69. Meyer, S., Gessner, D. K., Braune, M. S., Friedhoff, T., Most, E., Höring, M. et al. (2020). Comprehensive evaluation of the metabolic effects of insect meal from Tenebrio molitor L. in growing pigs by transcriptomics, metabolomics and lipidomics. *Journal of Animal Science and Biotechnology,* 11(1), Article 20. https://doi.org/10.1186/s40104–020–0425–7
70. Kowalska, D., Gugołek, A., Strychalski, J. (2020). Evaluation of slaughter parameters and meat quality of rabbits fed diets with silkworm pupae and mealworm larvae meals. *Annals of Animal Science,* 20(2), 551–564. https://doi.org/10.2478/aoas-2019–0080
71. Miah, M. Y., Singh, Y., Cullere, M., Tenti, S., Dalle Zotte, A. (2020). Effect of dietary supplementation with full-fat silkworm (Bombyx mori L.) chrysalis meal on growth performance and meat quality of Rhode island red × Fayoumi crossbred chickens. *Italian Journal of Animal Science,* 19(1), 447–456. https://doi.org/10.1080/1828051X.2020.1752119
72. Gugołek, A., Strychalski, J., Kowalska, D. (2019). Growth performance and meat composition of rabbits fed diets supplemented with silkworm pupae meal. *Spanish Journal of Agricultural Research,* 17(3), Article e0607. https://doi.org/10.5424/sjar/2019173–14882
73. Dalle Zotte. A., Singh, Y., Cullere, M., Gerencsér, Zs., Matics, Zs., Tenti, S. et al. (2021). Effect of dietary supplementation with silkworm (*Bombyx mori* L.) oil on fatty acid profile of rabbit meat. American Meat Science Association, (2021) "Abstracts from the 2020 International Congress of Meat Science and Technology and the AMSA Reciprocal Meat Conference", *Meat and Muscle Biology,* 5(2), 133. https://doi.org/10.22175/mmb.11683
74. Cullere. M., Singh, Y., Gerencsér, Zs., Matics, Zs., Cappellozza, S., Dalle Zotte, A. (2021) Silkworm (*Bombyx mori* L.) oil in growing rabbit nutrition: effects on meat physicochemical traits, sensory profile and shelf-life. *Journal of Insects as Food and Feed*. (unpublished data)

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Completely prepared the manuscript and is responsible for plagiarism

The author declare no conflict of interest.