PAPER • **OPEN ACCESS**

Meat quality of poultry fed with diets supplemented with insects: A review

To cite this article: Antonella Dalle Zotte 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **854** 012019

IOP Conf. Series: Earth and Environmental Science **854** (2021) 012019 doi:10.1088/1755-1315/854/1/012019

Meat quality of poultry fed with diets supplemented with insects: A review

Antonella Dalle Zotte[1]

[1] University of Padova, Department of Animal Medicine, Production and Health, Agripolis, Viale dell'Università 16, 35020 Legnaro, Padova, Italy

E-mail: antonella.dallezotte@unipd.it

Abstract. The development of sustainable feed ingredients for monogastric livestock is now also considering insect products. Although the regulation on the use of insect products differs among countries, resulting in restrictions on use in poultry diets, global research is exploring all the strengths and weaknesses of their inclusion. The scientific literature has extensively studied the relationship between insect-containing diet and effects on *ante-mortem* factors in fish and poultry, however the relationship between insect-containing diet and meat quality has only recently been considered. This review 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 poultry meat. The insect source in poultry diets rarely changed the related physicochemical variables or the sensory profile of the meat, whereas the fatty acid (FA) profile was the variable that was most affected, and inclusion of black soldier fly always resulted in meats with a more saturated FA profile, yellow mealworm in a more monounsaturated FA profile, whereas silkworm produced meat with a more unsaturated FA profile, rich in valuable omega-3 FA.

1. Introduction

Statistics about demographic trends depict that by 2050 the world population should reach 9.1 billion people. This scenario is putting pressure on the search for alternative and sustainable feed resources, and among them insects, for the livestock sector [1]. In addition to the above reason, the use of insects in avian species feeding is supported by the fact that about 80% of birds are reported to include insects in their diets [2]; such birds include chicken (*Gallus gallus*), turkey (*Meleagris gallopavo*), guinea fowl (*Numida meleagris*), quail (*Coturnix coturnix*), and ostrich (*Struthio camelus*), which are species of interest for food production in different regions of the world [3,4,5,6].

To exploit their maximum potential as feed ingredients, insects are processed to obtain whole insect meal (full-fat), protein meal (PAPs) which can be defatted or contain some proportion of lipids according to the extraction method, and fat/oil. The fatty acid (FA) profile of insect lipids can be very extreme: two examples are the black soldier fly (*Hermetia illucens*; BSF) and the silkworm (*Bombyx mori*; SW). The fat extracted from BSF larvae contains 60-79% saturated fatty acid (SFA). Conversely, the SW chrysalis is very rich in omega-3 PUFA [7], 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 [8]. The amino acid profile also differs between the different species of insects; in the case of the yellow mealworm (*Tenebrio molitor*; TM) 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 [9].

Research studies conducted so far have tested a wide range of levels of substitution (5-100%, mainly substitution of 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 [10].

2. Insects in poultry feeds and meat quality

The effects of including dietary insect products (larva meal, pre-pupa meal, oil) on the quality of food-producing terrestrial animals have been studied mainly in poultry. The purpose of this review is to provide updated literature on the use of insect-based products as feed for poultry broilers, detailing the effects on the physico-chemical-sensory quality of the meat obtained. The review will consider the BSF (*Hermetia illucens*), the TM (*Tenebrio molitor*), and the SW (*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.

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

The BSF larva is one of the most commonly used organisms for aquaculture and one of the best studied for both aquaculture and poultry feeding. The BSF larva averagely contains 43.1±5.05 g protein/100 g dry matter (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) [11]. 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 is provided below. Based on numerous studies (Table 1), the BSF as meal or fat in poultry diets has no [12,13,14,15,16,17,18,19,20,21] or limited influence [14,15,20,21,22,23] on physical meat quality (pH, colour, water holding capacity (WHC), shear force) of broiler chicken, quail, Barbary partridge, and Muscovy duck. Similarly, the poultry meat proximate composition also showed variable results, and they do not seem related to the insect meal inclusion level. Differences in meats' nutrient composition were mainly observed as more protein content [15,23], lowered [18] or increased [16,24] essential amino acids, and for enrichment in minerals, like calcium [24], sulphur [22], and copper [13]. In general, the sensory evaluation of poultry meat derived from animals fed diets supplemented with BSF did not differ from that obtained from control diets [14,17,24]. Instead, the BSF inclusion as meal or fat had a major contribution in modifying the FA profile of the lipids in the poultry meat [13,14,15,16,18,20,22,23,24,26,27]. The FA profile of the meat of monogastric animals is in line with the pattern of that of their diet, and the BSF (whatever its form) is rich in SFA, which make up approximately 70% of the total FAME, of which 43% constitutes C12:0 [21]. Therefore, it follows that the proportion of SFA in meat increases as a function of the dietary inclusion level of the BSF. In the majority of cases, this implies a worsening of the n-6/n-3 ratio [16], but either insect defatting or defatting their food substrate might not change [22] or could improve [18] the omega-6/omega-3 ratio. If the FA profile of the meat is changed by the inclusion of the BSF 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 BSF [13,24,26]. However it is interesting to note that [12] observed a significantly low TBARS value in 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 BSF in the diet.

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

The yellow mealworm (TM) larva meal is considered a nutritionally suitable substitute for fishmeal and soybean in aquaculture and poultry diets, although its cost is currently too high and it 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 [11] and potassium [9]. The fat (25-30% of TM meal) contains approximately 24% saturated FA, 24% polyunsaturated FA, and 50% monounsaturated FA, resulting in an omega-6/omega-3 ratio of 24 [9].

Contrasting results were obtained for physicochemical traits of meat from chicken broilers, apparently not depending on the inclusion level of TM meal (Table 2). However, the majority of the studies did not observe change in the meat pH, colour, moisture loss, shear force or fatty acid profile [28,29,30]. Instead, [31] observed that WHC, lipid and ash contents, TVB-N and sensory attributes worsened as the level of TM 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 TM inclusion levels, found adverse effects on sensory traits; on the contrary, [32] observed an improvement in meat juiciness and tenderness. When other poultry species were considered, such as Barbary partridge [20] and quail [33], no substantial differences in the meat physicochemical traits were observed due to the use of moderate to high levels of TM in the diet. Only meat colour changed in both bird species, although with an unclear pattern. The FA profile of the Barbary partridge meat was significantly affected by the dietary TM inclusion, particularly at the higher substitution level (50% of the soybean meal) [20]. FA changes resulted in the reduction of the C18:0 and omega-6/omega-3 ratio and the increase of C14:0, C15:0, C16:1, and C18:1 ($P<0.05$).

*2.3. 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% and 31.5% total FAME, in the full-fat and defatted meal, respectively), suggesting that it is a valuable nutritional ingredient for feed of different monogastric livestock species [7]. Silkworm pupa meal has been successfully included in chicken broiler diet (Table 3), as it produced no effect on colour values, lipid content [34] or on sensory attributes [28,32] of the meat. A slight effect was observed in lipid content (3.56 vs. 4.48% for leg meat of control and treated broilers, respectively) in the study of [28] and in protein and ash contents (however, differences were not coherent with the inclusion level; [34]). Meat pH increased with the SW meal inclusion level, but it did not impair meat colour [34]. The best result for the dietary inclusion of SW pupa meal in chicken diets 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 SW 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% SW meal inclusion levels, respectively ($P<0.05$; [34]).

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		0.5-1.0	NS	[12]
			50-75		NS	[1][14]
				5-15	NS	[15]
Colour[1; 2], TBARS[a], DPPH radical scavenging	chicken	meal		0.5-1.0	P<0.05	[12]
			25-50		P<0.05	[1][22]
				5-15	P<0.05	[2][15]
pH[1; 2], colour[1;2], lipid oxidation, cooking loss, shear force	chicken	meal		5-20	NS	[16]
				5	P<0.05	[1][23]
			50-75		P<0.05	[2][14]
Amino acid, FA[b] profiles	chicken	meal		5-20	P<0.05	[16]
FA profile	chicken	meal	25-50		NS	[22]
				5	P<0.05	[23]
			50-75		P<0.05	[14]
				5-15	P<0.05	[15]
Mineral profile	chicken	meal	25-50		P<0.05	[22]
Proximate composition	chicken	meal		5	P<0.05	[23]
			50-75		NS	[14]
				5-15	P<0.05	[15]
Sensory evaluation	chicken	meal	50-75		NS	[14]
pH, colour, WHC[c], proximate composition, amino acid, FA and mineral profiles, sensory evaluation	chicken	meal		5-15	NS	[17]
FA profile	chicken	fat	100		P<0.05	[25]
			50-100		P<0.05	[26]
			50-100		P<0.05	[27]
pH[1], thaw loss, proximate composition[1], TBARS	chicken	fat	50-100		NS	[26]
					NS	[1][27]
Cholesterol	chicken	fat	50-100		P<0.05/NS	[26]
Sensory evaluation	chicken	fat	50-100		NS	[26]
pH, colour, total moisture loss, shear force, heme iron, shelf life	quail	meal		10	NS	[18]
Proximate composition, cholesterol, amino acid, FA profiles, sensory evaluation	quail	meal		10	P<0.05	[18]
pH, colour, WHC, shear force	quail	meal	25-100		NS	[19]
Proximate composition, sensory evaluation, cholesterol, TBARS	quail	meal		10-15	NS	[24]
Mineral, FA, amino acid profiles	quail	meal		10-15	P<0.05	[24]
pH, cooking loss	quail	meal		10-15	P<0.05	[21]
Colour, shear force, amino acid profile	quail	meal		10-15	NS	[21]
pH, shear force, cook loss, proximate composition	Barbary partridge	meal	25-50		NS	[20]
Colour, FA profile	Barbary partridge	meal	25-50		P<0.05	[20]
pH, colour, proximate composition, TBARS	Muscovy duck	meal		3-9	NS	[13]
FA profile, mineral profile	Muscovy duck	meal		3-9	P<0.05	[13]

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

Table 2. 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	[28]
pH, colour, WHC[a], proximate composition, TVBN[b], sensory evaluation	chicken	meal		1-3	P<0.05	[31]
pH, colour, drip loss, proximate composition, FA[c] profile	chicken	meal		7.5	NS	[29]
pH, colour, WHC, shear force	chicken	meal		2-8	NS	[30]
Sensory evaluation	chicken	meal		8.1	P<0.05	[32]
pH, shear force, cook loss, proximate composition, cholesterol	Barbary partridge	meal	25-50		NS	[19]
Colour, FA profile	Barbary partridge	meal	25-50		P<0.05	[19]
WHC	quail	meal		7.5-30	NS	[33]
Colour	quail	meal		7.5-30	P<0.05	[33]

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

Table 3. 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	[28]
Colour	chicken	meal	25-50	7-14	NS	[34]
pH, proximate composition, FA[a] profile	chicken	meal	25-50	7-14	P<0.05	[34]
Sensory evaluation	chicken	meal		7.8	NS	[32]

[a]FA= fatty acids

3. Conclusions

The great economic impulse towards the use of insects as food and feed for ecological-environmental sustainability purposes 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 five years, much research has been conducted relating to the use of insects for alimentary use. Many of these studies 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 two 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 avian species. The results showed different effects, more depending on the insect species used than on the avian 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. Supplementary material. Rome pp 64

[2] Mwansat S, Turshak L G and Okolie M O 2015 Insects as important delicacy for birds: expanding our knowledge of insect food ecology of birds in the tropics. *J. Int. Sci. Publ. Ecol. Saf.* **9** 434–41
[3] FAO 2013 Edible insects – future prospects for food and feed security FAO Forestry Paper **171** IX
[4] Badenhorst A and Kerley G I 1996 Seasonal variation in the diet of common quail *Coturnix coturnix* in the Eastern Cape *Afr. Zool.* **31** 159–61
[5] Witt A R, Little R M and 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 *Agr Ecosyst & Environ* **55** 169–79
[6] Yassin O E, Gibril S, Hassan A H A and Bushara B A 2013 A study on Turkey (*Meleagris gallopavo*) raising in the Sudan. *Journal of Applied and Industrial Sciences* **1** 11–5
[7] Dalle Zotte A, Singh Y, Squartini A, Stevanato P, Cappellozza S, Kovitvadhi A, Subaneg S, Bertelli D and Cullere M 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** 100112
[8] Makkar H P, Tran G, Heuzé V and Ankers P 2014 State-of-the-art on use of insects as animal feed. *Anim. Feed Sci. Tech.* **197** 1–33
[9] Turck D, Castenmiller J, De Henauw S, Hirsch-Ernst K I, Kearney J, Maciuk A, Mangelsdorf I, McArdle H J, Naska 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 J.* **19** 6343
[10] Gasco L, Biasato I, Dabbou S, Schiavone A and Gai F 2019 Animals fed insect-based diets: State-of-the-art on digestibility, performance and product quality *Animals* **9** 170
[11] van der Heide M E, Stodkilde L, Norgaard J V and 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* **13** 2303
[12] Choi S U, Choi I H and Chung T H 2021 Investigation of breast meat traits of broilers fed different amounts of *Hermetia illucens* and *Protaetia brevitarsis seulensis* powder *Entomol. Res.* https://doi.org/10.1111/1748-5967.12504
[13] Gariglio M et al. 2021 Black soldier fly larva in Muscovy duck diets: effects on duck growth, carcass property, and meat quality *Poultry Sci.* 101303
[14] Altmann B A, Wigger R, Ciulu M and Morlein D 2020 The effect of insect or microalga alternative protein feeds on broiler meat quality *J. Sci. Food Agr.* 4292–302
[15] Schiavone A, Dabbou S, Petracci M, Zampiga M, Sirri F, Biasato I, Gai F and Gasco L 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** 2397–405
[16] de Souza Vilela J, Alvarenga T I R C, Andrew N R, McPhee M, Kolakshyapati M, Hopkins D L and Ruhnke I 2021 Technological Quality, Amino Acid and Fatty Acid Profile of Broiler Meat Enhanced by Dietary Inclusion of Black Soldier Fly Larvae *Foods* **10** 297
[17] Pieterse E, Erasmus S W, Uushona T and 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 *J. Sci. Food Agric*. **99** 893–903
[18] Cullere M, Woods M J, van Emmenes L, Pieterse E, Hoffman L C and Dalle Zotte A 2019b *Hermetia illucens* larvae reared on different substrates in broiler quail diets: effect on physicochemical and sensory quality of the quail meat *Animals* **9** 525
[19] Mbhele F G T, Mnisi C M and Mlambo V 2019 A nutritional evaluation of insect meal as a sustainable protein source for jumbo quails: Physiological and meat quality responses *Sustainability* **11** 6592

[20] Secci G, Moniello G, Gasco L, Bovera F and Parisi G 2018 Barbary partridge meat quality as affected by *Hermetia illucens* and *Tenebrio molitor* larva meals in feeds *Food Res. Int.* **112** 291–8
[21] Cullere M, Tasoniero G, Giaccone V, Miotti-Scapin R, Claeys E, De Smet S and Dalle Zotte A 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** 1923–30
[22] Kim B, Kim H R, Lee S, Baek Y-C, Jeong J Y, Bang H T and Ji S Y 2021 Park, S.H. 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** 665
[23] Popova T, Petkov E and Ignatova M 2020 Effect of Black Soldier Fly (*Hermetia illucens*) meals on the meat quality in broilers *Agr. Food Sci.* **29** 177–88
[24] Cullere M, Tasoniero G, Giaccone V, Acuti G, Marangon A and 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** 640–7
[25] Kim Y B, Kim D H, Jeong S B, Lee J W, Kim T H, Lee H G and Lee K W 2020 Black soldier fly larvae oil as an alternative fat source in broiler nutrition *Poultry Sci.* **99** 3133–143
[26] Cullere M, Schiavone A, Dabbou S, Gasco L and Dalle Zotte A 2019a 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** 140
[27] Schiavone A *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 *Ital. J. Anim. Sci.* **16** 93–100
[28] Pietras M, Orczewska-Dudek S, Szczurek W and 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 *Livest. Sci.* **250** 104537
[29] Dabbou S et al. 2020 Yellow mealworm (*Tenebrio molitor* L.) larvae inclusion in diets for free-range chickens: Effects on meat quality and fatty acid profile *Renew. Agr. Food Syst.* **35** 571–8
[30] Elahi U, Wang J, Ma Y, Wu S, Wu J, Qi G and Zhang H 2020 Evaluation of yellow mealworm meal as a protein feedstuff in the diet of broiler chicks *Animals* **10** 224
[31] Shaviklo A R, Alizadeh-Ghamsari A H and Hosseini S A 2021 Sensory attributes and meat quality of broiler chickens fed with mealworm (*Tenebrio molitor*). *J. Food Sci. Technol*. https://doi.org/10.1007/s13197-020-04946-w
[32] Khan S, Khan R U, Alam W and Sultan A 2018 Evaluating the nutritive profile of three insect meals and their effects to replace soya bean in broiler diet *J. Animal. Physiol. An. N.* **102** e662–e8
[33] Zadeh Z S, Kheiri F and 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*) *Vet. Anim* **8** 100066
[34] Miah M Y, Singh Y, Cullere M, Tenti S and 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 x Fayoumi crossbred chickens *Ital. J. Anim. Sci.* **19** 447–56