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Insect meal in poultry feed: a potential protein source

Jailson Novodworski[1*] Leandro Dalcin Castilha[2] and Alessandra Aparecida Silva[1]

[1]Programa de Pós-Graduação em Agroecologia, Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. [2]Departamento de Zootecnia, Universidade Estadual de Maringá, Maringá, Paraná, Brazil. *Author for correspondence. E-mail: jnjailson@ufpr.br

ABSTRACT. The present study aims to conduct a review on the potential use of insect meal as an alternative protein source in poultry feed, particularly to serve the rearing of free-range chickens. Insects are already part of the diet of birds in their natural habitat, and the availability of low-cost alternative foods with low environmental impact is essential for the development of the activity. The review comprehended studies that used meals consisting of silkworm (*Bombyx mori*) chrysalis, earthworm (*Eisenia foetida*), housefly (*Musca domestica*), black soldier fly (*Hermetia illucens*) and mealworm beetle (*Tenebrio molitor*) to replace plant-based protein sources. In general, insect meals have a high content of crude protein and ether extract, as well as an essential amino acid profile suitable for poultry feeding. The addition of insect meal in poultry feed normally shows good results as to growth performance and egg production, without causing a negative effect on carcass characteristics, meat sensory quality and egg quality, presenting itself as an alternative protein source with good prospects for replacing plant-based sources in poultry feed.

Keywords: alternative food; chickens; animal nutrition; protein.

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Introduction

Using insect meal as an alternative protein ingredient enables new perspectives for animal feeding, sparking a debate on sustainability combined with the quality of unconventional products (Reis & Dias, 2020). An efficient use of insects can close the cycle in a sustainable circular economy (Veldkamp et al., 2012), also constituting a highly nutritious and healthy food source, with a high content of protein, lipids, vitamins, fiber and minerals (Food and Agriculture Organization [FAO], 2013), which are considered a possible protein source for animal nutrition (Agazzi, Invernizzi, & Savoine, 2016), having an amino acid profile and essential amino acid indices similar to those of soybean meal (Veldkamp et al., 2012).

The high demand and consequent rise in the prices of fish and soybean meal has driven the development of research on protein sources from insects (FAO, 2013). Most insect species have high nutritional values with good amino acid profiles, and the use of insect pupae and larvae in poultry feed does not affect meat quality and the performance of growing animals (Zegeye, 2020). The inclusion of insects in animal feed usually provides good digestibility coefficient values. However, the presence of chitin in some insect species could lead to a decrease in nutrient digestibility, interfering with animal performance (Gasco, Biasato, Dabbou, Schiavone, & Gai, 2019).

In general, insects have great potential as a sustainable food resource in poultry nutrition, and their use is technically feasible (Khan, 2018). However, a lack of specific laws hinders their use. European Union regulations on feed with processed animal proteins make it difficult to use insects as protein sources for animal feeding (Babatunde, Park, & Adeola, 2021). In Brazil, Normative Instruction No. 110 was published in November 2020; among other specifications, it authorizes the use of some species of insects in animal feed, imposing levels of assurance and possible restrictions.

In the country, relevant rules and laws provide instructions on said management in accordance with animal behavior, and NBR 16389, 2015 (Associação Brasileira De Normas Técnicas [ABNT], 2015), specifies the requirements for primary production of free-range broiler chicken. Among other specifications, NBR 16389/2015 makes it a requirement to use slow-growing strains and that animal raised in facilities must have access to an outdoor area with pasture (minimum of 0.5 m² per housed bird). Access to pasture paddocks allows animals to come into contact with countless insects, termites, larvae, eggs, slugs, earthworms and an infinity of small animals; in addition, the consumption of these insects, which are highly appreciated by birds, is part of their natural eating habits, contributing in some way with the daily protein portion in their diets (Sales, 2005).

Thus, this review will address the potential use of insect meal as an alternative protein source in poultry feed to replace plant-based sources, especially to serve the rearing of free-range chickens, a promising market in the national scenario. The search for alternative sources of food, mainly energy and protein foods, is very important for the sustainable development of reared animals, as fluctuations in the market value of soybean meal make the use of alternative food sources increasingly indispensable.

Insect meal in poultry feed

Soybean meal is the protein source traditionally most used to formulate diets for broiler chicken; however, the search for alternative food sources has aroused the interest of several researchers worldwide in the use of insects as a sustainable alternative protein raw material, especially when insects are grown on substrates of organic waste and by-products (Veldkamp et al., 2012).

Considering a better sustainability of meat production, insects have rapidly emerged as an innovative food ingredient for some animal species, including poultry (Cullere et al., 2018). The most promising insect species for industrial feed production include silkworm pupae, housefly larvae, *Tenebrio molitor* larvae and blackfly larvae (Khan et al., 2016).

Silkworm (*Bombyx mori* L.) Chrysalis meal

Sericulture is an important agro-industrial activity, contributing substantially to the economy of several countries (International Sericultural Comission [INSERCO], 2020). Silk production generates a number of by-products, such as chrysalis (silkworm pupae), which in many countries are discarded after cocoon spinning (Buhroo et al., 2018). Silkworm chrysalis meal (SWCM) is obtained by grinding dry chrysalis and has an average of 56.19% of CP (crude protein), 24.9% of EE (ether extract) and 6.10% of ash (Table 1).

Table 1. Mean chemical bromatological composition of silkworm chrysalis meal (SWCM).**1**

	Unit	Mean	SD	Minimum	Maximum	N
Dry Matter (DM)[1]	% of food	92.29	1.81	89.90	94.40	5
Crude Protein[1]	DM %	56.19	4.24	50.20	61.25	5
Ether Extract[1]	DM %	24.92	6.26	18.66	33.50	5
Ash[1]	DM %	6.10	3.04	3.33	11.20	5

SD: standard deviation; N: number of studies observed; DM: dry matter. Source: [1](Qadri, Malik, Banday, Bhat, & Sharma, 2015; Ullah et al., 2018; Miah, Singh, Cullere, Tenti, & Dalle Zotte, 2020; Dalle Zotte et al., 2021; Pietras, Orczewska-Dudek, Szczurek, & Pieszka, 2021).

SWCM has been widely used in Asian countries to feed fish; in general, research carried out with non-ruminants shows that it is possible to use between 5 and 10% of the protein supplied in diets. When used in poultry feed to replace soybean meal, the literature has shown good results in terms of zootechnical performance (Novodworski, Guedin, & Silva, 2020), as one can see in Table 2, which refers to recent studies on the subject.

Table 2. Studies and effects of adding silkworm chrysalis meal (SWCM) to poultry feed.2

Country	Species/evaluated phase	Inclusion levels	Main results
Pakistan[1]	Laying hens (White Leghorn)	0 to 5.6%	Better productivity results with 2.8% inclusion.
Pakistan[2]	Broiler chicken (Ross 308) - 22 to 42 days	0 to 8%	6% inclusion presents better performance rates.
Pakistan[3]	Broiler chicken (Ross 308) - 1 to 28 days	0 to 8%	Better weight gain and feed intake with 6% inclusion.
Pakistan[4]	Laying hens (White Leghorn)	0 to 5.6%	The treatments did not affect feed intake, weight gain, feed conversion and egg production.
Italy[5]	Slow-growing broiler chicken (Rhode Island Red Fayoumi)	7% and 14%	7% inclusion showed better performance results.
Poland[6]	Broiler chicken (Ross 308) - 21 to 42 days	17%	It had no negative effect on growth performance and meat sensory quality.
Italy[7]	Japanese quail (Coturnix japonica) - 33 days old	12.50%	It showed no effect on the digestibility coefficient of crude protein and ether extract between the non-defatted SWCM and the control treatment. Presenting an adequate profile of fatty acids.

Source: Ullah et al. (2017a)[1]; Ullah et al. (2017b)[2]; Ullah, Khan, Khan, Tahir, and Ahmad (2018)[3]; Ullah, Khan, Khan, and Ullah (2020)[4]; Miah et al. (2020)[5]; Pietras et al. (2021)[6]; Dalle Zotte et al. (2021)[7].

Ullah et al. (2017) and Ullah et al. (2020) replaced up to 100% of soybean meal with SWCM for laying hens (White Leghorn). In both studies, increasing inclusion levels (0, 1.4, 2.8, 4.2 and 5.6%) of SWCM were used to replace soybean meal. Ullah et al. (2017) considered SWCM as a potential alternative ingredient to soybean meal, without affecting productive performance, nutrient digestibility, blood profile and egg quality, so the authors obtained the best productivity results with levels of 50% soybean meal replacement (2.8% inclusion). Ullah et al. (2020), in their turn, in addition to identifying that adding SWCM to the diet did not affect feed intake, weight gain, feed conversion and egg production, also did not find any significant difference in intestinal health between the evaluated groups.

As for broiler chickens, Ullah, Khan, Hafeez, et al. (2017) and Ullah et al. (2018) used in their studies increasing inclusion levels of SWCM (0, 2, 4, 6 and 8% of the total of the diets) replacing soybean meal. In the initial growth phase of the birds (1 – 28 days), the inclusion of 6% of SWCM (75% soybean meal replacement) provided better growth performance rates, without affecting the sensory quality of the meat (Ullah et al., 2018). According to the researchers, chrysalis meal has been shown to be a rich source of crude protein, crude fat and essential amino acids, including lysine and methionine. In the final rearing phase (22 – 42 days), the best weight gain and feed intake of the birds was found with diets containing 6% SWCM inclusion, with no changes in feed conversion and carcass quality (Ullah, Khan, Hafeez, et al., 2017). By replacing 100% of soybean meal with SWCM and lupin flour (17 and 20% inclusion, respectively), Pietras et al. (2021) did not identify changes in weight gain and feed conversion in the final rearing stage (21 – 42 days) of the chickens, and there was no difference in meat sensory quality.

In a study with slow-growing birds (Rhode Island Red and Fayoumi crossbred), Miah, Singh, Cullere, Tenti, and Dalle Zotte (2020) assessed the effects of a diet containing increasing inclusion levels (0, 25 and 50%) of chrysalis meal replacing soybean meal and oil, representing levels of 7 and 14% of total inclusion in the diet. The authors concluded that SWCM is a rich source of crude protein, providing lipids with a high amount of omega-3 fatty acids that can be used to replace 25% of soybean meal (7% inclusion in the diet) in chicken feed, enabling good growth performance without affecting carcass characteristics.

Dalle Zotte et al. (2021) evaluated the digestibility coefficient of silkworm chrysalis meal (SWCM), both defatted (63.7% CP and 9.49% EE) and non-defatted (53.9% CP and 29.1% EE), replacing soybean meal, with an inclusion of 12.5% in the diet of Japanese quails (*Coturnix japonica*). The authors observed a remarkable proportion of polyunsaturated fatty acids in the SWCM, which presented a healthier fatty acid profile comparable to that of the control treatment, corroborating the results of Ullah et al. (2018) and Miah et al. (2020). According to Dalle Zotte et al. (2021), the presence of 3.0-3.6% chitin in SWCM may be one of the causes of the negative general effect on the digestibility coefficient of nutrients, but there was no change in the digestibility coefficient of CP and EE between non-defatted SWCM and the control treatment.

Earthworm meal (*Eisenia foetida*)

Earthworms (*Eisenia foetida*), commonly grown to recycle different sources of organic waste, are also an excellent source of low-cost alternative protein (Vielma-Rondón, Ovalles-Duran, León-Leal, & Medina, 2003). The nutritional composition of earthworm meal (Table 3) shows its potential as an alternative protein source in poultry diets, containing high levels of crude protein (approximately 60%), in addition to minerals and an amount of essential amino acids that is adequate for poultry farming, values which compare favorably with those of fish meal (Moreki & Tiroesele, 2012) and are superior to those of soybean meal (Cancian et al., 2020).

Table 3. Mean chemical bromatological composition of earthworm meal (EM).3

	Unit	Mean	SD	Minimum	Maximum	N
Crude Protein[1]	DM %	59.97	6.10	51.62	65.68	4
Ether Extract[2]	DM %	6.90	0.93	5.90	7.76	3

SD: standard deviation; N: number of studies observed; DM: dry matter; Source: [1](Moreki & Tiroesele, 2012; Bahadori, Esmaylzadeh, & Torshizi, 2015; Valente, Xavier, Morselli, & Lopes, 2015; Gunya, Muchenje, & Masika., 2019); [2](Moreki & Tiroesele, 2012; Bahadori et al., 2015; Gunya et al., 2019).

Studies point to a better protein digestibility coefficient, as well as better indices of performance results when earthworm meal protein is used replacing soybean meal (Rezaeipour, Nejad, & Miri, 2014). The inclusion of EM in the diet of broilers can provide greater weight gain (Bahadori et al., 2017; Gunya et al., 2019) and a reduction in feed conversion (Rezaeipour et al., 2014; Bahadori et al., 2017). When used in poultry feed, studies have shown good results in terms of zootechnical performance, and meat and egg quality parameters (Table 4).

Table 4. Studies and effects of adding earthworm meal (EM) to poultry feed.4

Country	Species/evaluated phase	Inclusion levels	Main results
Iran[1]	Broiler chicken (Ross) - up to 42 days	0 to 10%	It improved weight gain, feed conversion and feed digestibility.
Iran[2]	Broiler chicken (Ross 308) - 1 to 42 days	0 to 3%	It improved feed conversion and did not affect carcass characteristics.
South Africa[3]	Broiler chicken (Cobb) - 01 to 35 days	0 to 10%	Used in the diet of broilers without a deleterious effect on carcass characteristics and meat quality attributes.
Brazil[4]	Laying hen - 50 weeks old	0 to 4%	As a result, the proposed replacement resulted in better indices of egg weight, yolk color, yolk weight, and shell thickness and strength.

Source: Rezaeipour et al. (2014)[1]; Bahadori et al. (2017)[2]; Gunya et al. (2019)[3]; Cancian et al. (2020)[4].

The inclusion of EM in the diet of the birds does not affect carcass composition; in plasma biochemistry analyses of the blood of broilers, the total levels of protein, albumin, Ca and P increased in the chickens fed EM (Bahadori et al., 2017). In addition, the treatments showed a positive influence on serum cholesterol and on uric acid in broilers compared to the control treatment. Gunya et al. (2019), in their turn, identified that an inclusion of 5% EM in the diet of birds beneficially influenced carcass and breast characteristics, while visceral organs showed better results in diets containing 10% inclusion. Thus, the authors suggested that earthworm meal can be used in the diet of broiler chickens without adverse effects on carcass characteristics and meat quality.

In laying hens, the inclusion of earthworm meal resulted in better indices for these variables: egg weight, yolk color, yolk weight, and shell thickness and strength (Cancian et al., 2020). These changes are related to the nutritional quality of EM; the authors explain that the size of the egg and the color of the yolk may be related to the higher content of tryptophan present in the diet with EM, and that the greater weight of the yolk is due to the greater availability of the amino acids that phosphorylate with phosphovitin, which corresponds to the granular fraction of the yolk, while the greater thickness and strength of the shell may have occurred due to the solubility of the calcium (Ca) present in EM.

Housefly (*Musca domestica*) larvae meal

The housefly (*Musca domestica*) is considered a cosmopolitan insect species (Ortiz et al., 2011), having a high capacity to adapt to the environmental changes caused by man (Britto et al., 2008). Housefly larvae, in addition to having a high content of crude protein and ether extract (Table 5), also bring the benefit of reducing the organic matter used in their rearing (in the order of 40-50%), facilitating and potentiating their use as agricultural fertilizers (Uushona, Simasiku, & Petrus, 2019).

Table 5. Mean chemical bromatological composition of housefly larvae meal (HFM).5

	Unit	Mean	SD	Minimum	Maximum	N
Crude Protein[1]	DM %	51.51	10.03	37.20	60.38	4
Ether Extract[1]	DM %	22.44	11.15	12.28	7.15	4
Ash[1]	DM %	10.18	2.35	35.50	12.84	4

SD: standard deviation; N: number of studies observed; DM: dry matter; Source: [1](Adeniji, 2007; Pieterse & Pretorius, 2014; Khan et al., 2016; Uushona et al., 2019).

Housefly meal (HFM) has great potential as a possible sustainable protein source and alternative in diets for poultry farming, providing animals with a large amount of energy and proteins, having a profile of essential amino acids that meets the nutritional requirements of birds (Pieterse & Pretorius, 2014), in particular, higher amounts of lysine, threonine and methionine compared to plant-based sources (Khan et al., 2016; Gadzama & Ndudim, 2019). In general, when used in poultry feed replacing plant-based protein sources, HFM has shown good productive results (Table 6).

The inclusion of HFM in the diet of broilers replacing plant-based protein sources provides an increase in the digestibility coefficient of dry matter, crude protein, crude fiber and ether extract (Khan, Chand, Khan, Khan, & Sultan, 2018). Likewise, apparent metabolizable energy is higher for birds fed diets containing HFM (Khan et al., 2016; Khan et al., 2018). These factors have a direct impact on the animals' zootechnical performance indices, with no changes being observed in weight gain, feed intake and feed conversion with the inclusion of HFM in the diet, or even better results, with positive impacts on these indices (Khan et al., 2016; Khan et al., 2018). Another positive factor refers to meat quality, with no differences being observed with regard to flavor, tenderness, juiciness, color and flavor of the meat of poultry fed diets containing HFM at total inclusion levels of up to 6% (Khan et al., 2018).

Table 6. Studies and effects of adding housefly meal (HFM) to poultry feed.6

Country	Species/evaluated phase	Levels of inclusion in the diet	Main results
Nigeria[1]	Broiler chicken - 01 to 42 days	0 to 22%	It can be used to replace up to 100% of peanut pie (22% inclusion) without interfering with weight gain, feed intake and feed conversion.
South Africa[2]	Broiler chicken (Cobb 500) - 20 days old	Nutritional assessment	Total digestibility coefficient, nutritional composition (amino acid profile), fatty acid composition.
Pakistan[3]	Broiler chicken (Ross 308) - 01 to 28 days	0 to 3%	It can be used at all inclusion levels, without interfering with performance and carcass quality.
Pakistan[4]	Broiler chicken (Ross 308) - 01 to 28 days	0 to 6%	It improved weight gain and feed conversion, providing good results in terms of digestibility coefficient and apparent metabolizable energy, without interfering with the sensory quality of the meat.

Source: Adeniji (2007)[1]; Pieterse and Pretorius (2014)[2]; Khan et al. (2016)[3]; Khan et al. (2018)[4].

Black soldier fly (*Hermetia illucens*) larvae meal

The black soldier fly (*Hermetia illucens*) has an almost cosmopolitan distribution (except in cold regions), with no adverse environmental impact (Syromyatnikov, Lopatin, Danshina, & Popov, 2021). Black soldier fly larvae contain a relatively high amount of protein and lipids, which makes them a suitable source for animal feeding, containing 42.9% Crude Protein, 26.9% Ether Extract and 10.9% ash. (Table 7).

Table 7. Mean chemical bromatological composition of black soldier fly larvae meal (BSFM).7

	Unit	Mean	SD	Minimum	Maximum	N
Crude Protein[1]	DM %	41.14	3.90	36.20	46.30	6
Ether Extract[1]	DM %	26.63	10.49	11.90	36.90	6
Ash[2]	DM %	10.85	2.78	7.87	15.30	5

SD: standard deviation; N: number of studies observed; DM: dry matter; Source: [1](Barroso et al., 2014; De Marco et al., 2015; Mohammed, Larya, Ganiyu, & Adongo, 2017; Gougbedji, Agbohessou, Laleye, Francis, and Caparros Megido, 2021; Ebeneezar et al., 2021; Patterson et al., 2021); [2](Barroso et al., 2014; Mohammed et al., 2017; Gougbedji et al., 2021; Ebeneezar et al., 2021; Patterson et al., 2021).

In poultry feed, the inclusion of BSFM (black soldier fly meal) has been used to replace plant-based sources, such as soybean meal and oil, providing good results in terms of zootechnical performance, without interfering with meat and egg quality characteristics, as shown in Table 8.

Table 8. Studies and effects of adding black soldier fly meal (BSFM) to poultry feed.8

Country	Species/evaluated phase	Levels of inclusion in the diet	Main results
Italy[1]	Quail (*Coturnix japonica*) - 10 to 28 days old	0 to 15%	It can be used in up to 15% of the diet, providing quality meat.
Germany[2]	Broiler chicken (Ross 308) - 01 to 35 days old	50% of soybean meal	Better weight gain compared to the control group, not interfering with the physicochemical parameters of the meat.
Italy[3]	Broiler chicken (Ross 308) - 1 to 35 days	0 to 15%	A 10% level positively influenced the growth and performance of the birds in the initial phase.
Malaysia[4]	Broiler chicken (Cobb 500) - 01 to 21 and 22 to 42 days	0 to 10%	The inclusion resulted in an improvement in the zootechnical performance indices, not changing carcass characteristics.
Canada[5]	Pullets (White Leghorn) - 19 to 27 weeks old	0 to 7.5%	It did not change the daily production and weight of the eggs, with an increase in eggshell thickness, but there was an increase in feed conversion.
South Africa[6]	Broiler chicken (Cobb 500) - 01 to 35 days old	0 to 15%	No changes were identified in carcass weight, sensory analysis and meat quality characteristics.
Italy[7]	Broiler chicken (01 to 35 days old)	0 to 15%	It can be used in up to 10% of inclusion in the diet without causing changes in carcass weight and meat quality parameters.
Germany[8]	Broiler chicken (Ross 308) - 01 to 35 days old	50% and 75% of soybean meal	It provided a positive effect on weight gain, as well as a significant effect on the proportion of saturated fatty acids in the thigh meat of the birds, with no changes in meat sensory quality.

Source: Cullere et al. (2018)[1]; Altmann, Neumann, Velten, and Liebert (2018)[2]; Dabbou et al. (2018)[3]; Kareen et al. (2018)[4]; Mwanik et al. (2018)[5]; Pieterse et al. (2019)[6]; Schiavone et al. (2019)[7]; Altmann, Wigger, Ciulu, and Mörlein (2020)[8].

As for weight gain, with the exception of Pieterse, Erasmus, Uushona, and Hoffman (2019) and Schiavone et al. (2019), who did not observe any change in relation to the control treatment, studies have shown a positive effect with the inclusion of BSFM in the diet of the birds (Altmann et al., 2018; Dabbou et al., 2018; Kareem et al., 2018; Altmann et al., 2020). On the other hand, levels of BSFM inclusion in up to 10% of the diet can improve their FC (feed conversion) (Dabbou et al., 2018; Kareem et al., 2018), but higher levels can lead to an increase in FC (Dabbou et al., 2018). However, this change may be related to the presence of high levels of chitin in the larvae of the black soldier fly, which is part of its exoskeleton and is not digestible by monogastric animals, affecting protein digestibility (Dabbou et al., 2018; Altmann et al., 2020).

Meat quality is one of the most important factors to be analyzed when including an alternative food in animals' diet; there is agreement among several researchers that the inclusion of BSFM does not change carcass characteristics (Kareem et al., 2018), the physicochemical parameters of the meat (Altmann et al., 2018; Schiavone et al., 2019) and its sensory quality (Pieterse et al., 2019; Altmann et al., 2020). However, Altmann et al. (2018) identified a slightly stronger flavor in the meat of birds fed BSFM, concluding that this is a positive factor, since consumers can appreciate this characteristic of the meat. Despite not identifying changes in the sensory quality of poultry meat, Altmann et al. (2020) found an increase in thigh fatty acids, a result similar to that reported by Cullere et al. (2018), who identified changes in the fatty acid profile of quail meat.

In laying hens aged between 19 and 27 weeks, a 7.5% inclusion of defatted BSFM (6% of ether extract) in a diet based on corn and soybean meal may lead to an increase in feed intake and feed conversion, without interfering with daily egg production and egg weight; consequently, the inclusion of BSFM provides greater eggshell thickness and increased yolk color intensity (Mwaniki, Neijat, & Kiarie, 2018). These factors can generate positive impacts on egg production, as shown by Secci et al. (2018), who reported that chickens fed diets containing 17% BSFM inclusion produced eggs with a higher proportion of yolk and a more intense red color; in addition, the yolks contained 11% less cholesterol than those in the control group.

Cullere et al. (2018) conducted a study to assess the effect of partial replacement of soybean meal and oil with defatted BSFM (*Hermetia illucens*) in the diet of growing meat-type quails (*Coturnix japonica*) (10 to 28 days of age) by evaluating the proximal composition of the meat, cholesterol, amino acid and mineral content, fatty acid profile, oxidative status and sensory characteristics. The authors found that, regardless of the inclusion level, there was no change in the chemical composition and oxidative state of the meat, but there was a linear increase in calcium content and a reduction in potassium content proportionally to the increase in the inclusion level. This was the first study to evaluate the sensory attributes of meat of quail fed BSFM, with no changes being identified regarding odor, flavor and texture attributes (Cullere et al., 2018). Thus, the authors concluded that the inclusion of up to 15% of BSFM in the diet is technically feasible, producing meat of similar quality to that of quails fed conventional diets.

***Tenebrio molitor* meal**

The mealworm beetle (*Tenebrio molitor*) is native to Europe and widespread in the world (Ramos-Elorduy, 2008). The rearing of *Tenebrio molitor* larvae does not require much space or special management and equipment, and can be handled at home (Costa-Neto, 2003). Its larvae have a high content of crude protein and ether extract (Table 9), also constituting a rich source of metabolizable energy and digestible amino acids in broiler diets (De Marco et al., 2015).

Table 9. Mean chemical bromatological composition of *Tenebrio molitor* larva meal (TMM).9

	Unit	Mean	SD	Minimum	Maximum	N
Dry Matter (DM)[1]	% of food	93.65	2.16	89.91	95.40	5
Crude Protein[2]	DM %	54.19	6.44	45.83	63.67	6
Ether Extract[2]	DM %	27.97	4.99	21.57	34.20	6
Ash[3]	DM %	3.82	1.23	2.51	4.69	4

SD: standard deviation; N: number of observations; DM: dry matter; Source: [1](De Marco et al., 2015; Bovera et al., 2016; Hussain et al., 2017; Elahi et al., 2020; Pietras et al., 2021); [2](Barroso et al., 2014; De Marco et al., 2015; Bovera et al., 2016; Hussain et al., 2017; Elahi et al., 2020; Pietras et al., 2021); [3](Barroso et al., 2014; Bovera et al., 2016; Hussain et al., 2017; Pietras et al., 2021).

Tenebrio molitor larva meal (TMM) has great potential as an alternative protein source in poultry feed; there is agreement among the various authors regarding the feasibility of its use, as shown in Table 10.

Table 10. Studies and effects of adding *Tenebrio molitor* larva meal (TMM) to poultry feed.10

Country	Animal/evaluated phase	Inclusion level	Result
Italy[1]	Broiler chicken (Ross 308) - 26 days old	Digestibility coefficient	Data on the digestibility of nutrients with contents of digestible amino acids and metabolizable energy.
Italy[2]	Broiler chicken (Label Hubbard) 43 to 97 days	7.5%	It did not influence the birds' performance, and blood and serum characteristics.
Italy[3]	Broiler chicken (Shaver Brown) - 30 to 62 days	29.65% (100% of soybean meal)	It improved the feed conversion of the birds, not interfering with weight gain, carcass characteristics and the physicochemical quality of the meat.
Italy[4]	Broiler chicken (Ross 708) - 01 to 53 days	5%, 10% and 15%	It improved weight gain and feed intake, negatively affecting feed conversion, without changing carcass characteristics or the hematological and serum parameters of the birds.
Turkey[5]	Quail - 7 to 35 days	0 to 6%	Inclusion levels above 2% can negatively affect animal performance indices.
China[6]	Broiler chicken (Ross 308) - 01 to 42 days	0 to 8%	The inclusion at the level of 4% showed better performance indices, not affecting carcass quality and hematological characteristics.

Source: De Marco et al. (2015)[1]; Biasato et al. (2016)[2]; Bovera et al. (2016)[3]; Biasato et al. (2018)[4]; Cufadar and Sabirli (2019)[5]; Elahi et al. (2020)[6].

Biasato et al. (2018) assessed the effects of including TMM (0, 5, 10 and 15%) as an alternative protein source in the diet of broilers (Ross 708). According to the authors, this was the first study in which broilers were fed diets with TMM during the entire rearing phase, from housing to slaughter, which occurred at 53 days of age. Regardless of the inclusion level, there was no change in the biochemical, hematological and serum parameters of the birds, confirming the safety of the animals' diet. The authors concluded that increasing levels of TMM inclusion in the diet of broilers can improve weight gain and intake, but it had a negative effect on feed conversion. Thus, the authors suggest that levels below 5% inclusion would be more adequate. These results are in agreement with Elahi et al. (2020), who obtained the best performance result in broiler chickens (ROSS 308) with 4% TMM inclusion. Pietras et al. (2021), in their turn, by including 17% of TMM and 20% of lupin flour replacing soybean meal, identified a reduction in feed conversion, without influencing the sensory quality of the meat.

Biasato et al. (2016) included 7.5% of TMM in the diet of slow-growing broilers (Label Hud-bard - JA57 strain) between 43 and 97 days of age. According to the authors, TMM can be used safely to feed the birds, not interfering with their zootechnical performance, and blood and serum characteristics. Also using a slow-growing strain (Shaver brown), Bovera et al. (2016) replaced 100% of soybean meal with TMM (29.65% of the diet). The authors observed a lower digestibility coefficient than that of soybean meal, but this reduction in nutrient digestibility had no effect on the performance results of the chickens, not influencing weight gain and providing a reduction in feed conversion, without changing carcass characteristics and the physicochemical quality of the meat.

Evaluating the growth performance and carcass characteristics of quails (from 7 to 35 days of age), Cufadar and Sabirli (2019) included increasing levels (0, 2, 4 and 6%) of TMM replacing soybean meal for quails. The authors observed that feed intake did not differ between treatments, but there was an increase in feed conversion in diets containing 4 and 6% insect meal inclusion. On the other hand, with a 2% inclusion, the birds had a greater weight gain compared to the other treatments, but the weight gain was lower with 4 and 6% inclusion. Thus, they concluded that it is possible to use up to 2% TMM inclusion in quail diet, and higher levels can affect the performance of the birds, causing a reduction in weight gain and an increase in feed conversion, without interfering with feed intake.

Conclusion

There is agreement among the different authors on the high nutritional value of insect meals, which have great potential as an alternative protein ingredient, a high content of crude protein and ether extract, in addition to an amino acid profile and fatty acid composition suitable for feeding the birds. In general, insect meals can be included in poultry diets, with no adverse effect on animal performance indices, carcass characteristics or meat sensory quality. However, high levels of inclusion of these meals should be avoided so as not to increase feed conversion and reduce nutrient digestibility, mainly due to the presence of chitin in insect meals. In a scenario where the population is growing, the need for food increases every day, so insect meals represent sustainable and low-cost food sources for feeding birds in general.

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