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Potential use of the Black Soldier Fly (BSF) in Poultry Production

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ABSTRACT
The aim of this article is to encourage debate and sharing of studies and research on the use of Black Soldier Fly (BSF) in poultry feed. It is observed that in Brazilian poultry, feeds are mainly based on cereals, which must be supplemented with high quality animal protein and essential amino acids. Among the alternative ingredients for monogastric diets, the use of insects has stood out and among the insects used, black soldier fly flour or BSF (Hermetia illucens) is an attractive candidate, as it contains excellent nutritional characteristics and high production of biomass, in addition to its ability to promote the degradation of a series of materials of organic origin, converting them into an important source for animal feed. It is concluded that, although promising as a food component in the diet of poultry, the current cost to produce these insects in the country is still high and a relevant factor when compared to sources such as fish meal and soybean meal. Other challenges, such as the standardization of the bromatological compositions of flours derived from these insects, increased production, as well as a cultural change in the Western way of seeing these organisms, are issues to be addressed.

Keywords: Alternative foods, Broiler chickens, Insects in animal feed, Nutrition of monogastrics, Layers, Black soldier fly.

1 INTRODUCTION

One of the main challenges of current animal nutrition is the search for methods of formulating rations that meet the needs of animals, with efficiency, economy and sustainability. The formulation of modern diets is mainly aimed at providing food with a nutrient density to achieve high animal performance, while limiting costs and, all this, minimally interfering with the environment.

In Brazilian poultry farming, the rations are mainly based on cereals and should be supplemented with high quality animal protein and/or essential amino acids. Among the alternative ingredients for monogastric diets, the use of insects has stood out, since it is a sustainable source allied to its characteristic of presenting quality as a source of protein (CULLERE et al., 2016).

There are more than 1,900 species of insects cataloged with potential use for animal and human food (VAN HUIS, 2013b). Insects are already part of the natural diet of wild birds and raised outdoors, so they are a great alternative for nutritionally compatible feeding with fishmeal (JANTZEN DA SILVA LUCAS et al., 2020).

In relation to their production in scale, they are organisms that are not demanding in space, which reproduce and grow in mass populations and in a short time. Added to this, they are associated with high feed efficiency and the reduction of greenhouse gas emissions, when compared with animals from conventional farms, making them potent candidates as a food and component of animal diets (EWALD et al., 2020; VAN HUIS, 2013).

Among the insects used, black soldier fly flour (***Hermetia illucens***) contains excellent nutritional characteristics and high biomass production (REIS et al., 2020).

Although there is a great search for alternative strategies for animal feed, especially with regard to potential substitutes for protein sources, the use of insects in the feeding of monogastric animals is still relatively recent in the country. For all this, the objective of this article was to incite debate and the sharing of studies and research on the use of the Black Soldier Fly (BSF) in the feeding of production birds.

2 INSECTS: CHARACTERIZATION AND RELEVANCE

Insects constitute about three-quarters of the total organisms present on Earth (PEDIGO, 2002). The class of insects (phylum Artropoda) hosts the greatest diversity of animal life (about 90%) existing on the planet, with more than one million species of insects described and cataloged. The insects can be divided into orders such as Diptera (black soldier fly, housefly), Coleoptera (tenebrio), and Orthoptera (grasshoppers and crickets), Blattaria (cockroaches) and Lepidoptera (silkworm and moth) (RUMPOLD; SCHLÜTER, 2013).

More than 2000 species around the world are recognized as "edible insects" for having rich nutritional value, nutraceutical properties (antimicrobial peptides) and for not transmitting diseases or being poisonous, making them fit for consumption (GLOVER & SEXTON, 2015; VAN HUIS, 2015).

Generally, insects are satisfactory sources of nutrients to farm animals, such as protein, fat, energy, vitamins and minerals. In addition, they have short life cycles, are easy to produce and handle (ARANTES; MARCHINI; KAMIMURA, 2021; RAMOS-ELORDUY et al., 2002).

From an environmental point of view, mass insect production is promising, due to the low levels of greenhouse gas emissions (OONINCX; VAN HUIS; VAN LOON, 2015), to the fact that they require a small area to produce 1 kg of protein (OONINCX; DE BOER, 2012), have excellent feed efficiency and ability to convert organic waste into protein of high biological value (MENEGUZ; GASCO; TOMBERLIN, 2018).

3 INSECTS AS A HUMAN AND ANIMAL FOOD ALTERNATIVE

Although its use in human and/or animal food sounds exotic in the Western world, it is an age-old practice in the East that feeds more than two billion people. In fact, it is not a matter of introducing the idea of insects as food, but of modifying the concept inserted in Western society (VAN HUIS, 2013).

The development of systems of mass rearing of insects, in the face of the current crisis and rising food prices, offers interesting perspectives for their use for different purposes, such as animal and human food. The culture of insects is interesting, since it does not compete with food resources or land use, in addition, it promotes nutrient recycling, transforming waste, which previously would provide greater environmental pollution, into foods with high nutritional content (SANCHEZ-MUROS; MUDDY; MANZANO-AGUGLIARO, 2014).

Food insects are emerging as an innovative food ingredient for some species of farm animals, especially poultry and pigs, and are an excellent alternative to protein vegetables, meat, viscera and fish meal (CULLERE et al., 2019; LOCK; BIANCAROSA; GASCO, 2018).

The nutritional requirements of monogastric species, particularly poultry, include a high quality and quantity of protein in the diet. The main protein ingredients added in the monogastric feed are animal flours and soybean meal. Soy meal has high digestibility, quality and quantity of protein, and the best amino acid profile among available plant protein sources, along with other nutritious benefits (WEBSTER et al., 1995).

Despite this, according to these same authors, foods of plant origin have several unfavorable characteristics, such as imbalances between essential and non-essential amino acids, anti-nutritional factors, low palatability and a high proportion of non-starchy fibers and polysaccharides, which limit the percentage of inclusion in the diet. In these conditions, it becomes necessary to supplement the diet by adding amino acids or a high-value protein source, such as animal protein, which has high digestibility and a good balance between essential and non-essential amino acids. Insects present a large amount of protein, ranging from 35% in termites to 68% in crickets in MS, and lipids, with crickets presenting about 13% and beetle larvae 50%, also in MS (WEBSTER et al., 1995).

To make use of insects as a food ingredient on a large scale, it is important to increase the production of insects, in continuous quantity and quality, but one must decrease the cost price of breeding in order for it to become competitive with the protein sources currently used. The published results on the use of insect meal in animal feed indicate that these have great potential as food, especially because they are an excellent source of protein and contain an adequate amino acid profile, depending on the species of insect (SÁNCHEZ-MUROS et al., 2014).

Insects are considered an alternative source of protein, fat, energy, vitamins and minerals, as well as being potential substitutes for fishmeal and soybean meal in animal feed. To date, major research efforts have focused on the species: Black Soldier Fly (BSF), housefly, beetle ***Tenebrio molitor***, grasshoppers, crickets, cockroaches, silkworm larvae, and their processing. No negative effects have been reported on nutrient performance and digestibility in animals fed insect meal (ARANTES; MARCHINI; KAMIMURA, 2021).

In the case of animal meal (FOA), sensory specifications should focus on characteristics such as color, odor, particle size aspect, moisture, and fat to the touch. To date, there is still no news of processes of registration of insect meal completed with the Ministry of Agriculture, Livestock and Supply (MAPA), but the insects are admitted for use in production animals (BELLAVER et al., 2006).

4 BLACK SOLDIER FLY (BSF) – "MOSCA- SOLDADO- NEGRA"

Among the insects used in animal feed, the Black Soldier Fly (BSF) stands out (***Hermetia illucens***), a Diptera of the family *Stratiomyidae*, being indigenous to the tropical, subtropical, and warm zones of the Americas, but is distributed throughout the world (CULLERE et al., 2016; SCHIAVONE et al., 2017).

BSF is an extremely hardy species, capable of living in demanding environmental conditions such as drought, food shortages or oxygen deficient (MAKKAR et al., 2014), in addition to not being a vector of diseases (ABD EL-HACK et al., 2020). As adults, flies do not feed except to drink water, and the nutrition is necessary for reproduction acquired during larval development.

After mating, females produce on average 320-620 eggs, which are deposited in decaying organic matter, and die within a few hours (TOMBERLIN; ADLER; MYERS, 2009). The eggs take on average 4.3 days to hatch at a temperature of 24°C and the nutritional composition of the substrate used in breeding determines the amount of larvae introduced. The pre-pupa is the last stage of larval development, and it is at this stage that a large amount of fat is stored that will be used to provide energy for its transformation into an adult fly (ABD EL-HACK et al., 2020).

As for size, a BSF larva can reach 27 mm in length, 6 mm in width and 220 mg in weight in its last larval stage. They can be fed 25 to 500 mg of fresh matter/larva/day of substrates (BARRY, 2004).

In nature, manure is the main organic matter for BSF farming. In addition to not being a vector of disease, BSF are able to feed on a variety of organic materials such as animal manure, brewery byproducts, restaurant waste, decaying organic materials such as fruits and vegetables, coffee pulp and beans, distillery beans, fish offal, human excreta and sewage sludge, turning waste into valuable biomass (CULLERE et al., 2016; EWALD et al., 2020; MAKKAR et al., 2014).

It has been shown that the rearing of BSF larvae leads to a significant reduction in the moisture of the garbage, in the volume of residues, in the offensive odor, in the elimination of the Moscow-from-home,***Domestic Musca L.*** and in lesser action, but also acting upon the house fly,***Fannia canicularis***, (ABD EL-HACK et al., 2020).

5 NUTRITIONAL CHARACTERISTICS OF BSF (BLACK SOLDIER FLY)

The black soldier fly (***Hermetia illucens***) is a popular bio-recycling organism, being able to convert large amounts of organics, pollutants and substrates in food or animal waste into edible proteins and fats during its growth (ZHENG et al., 2012). Blackfly larvae (**BSFL**) contains up to 40% proteins rich in essential amino acids, more than 28% lipids and minerals such as Ca and P (MAKKAR et al., 2014; WANG; SHELOMI, 2017).

In contrast to the nutritional advantage, the potential danger of insects used as animal feed has also been reported because of the accumulation of heavy metals and toxins when the insects were grown on contaminated substrates and should be better elucidated (WANG and SHELOMI, 2017).

BSF larvae (BSFL) are used in different stages or in the pre-pupa stage, live, or processed, dehydrated and ground in the form of whole BSFL flour or partially defatted BSFL. Different types of food used in BSF breeding can influence the chemical composition of the BSF larva (OONINCX; VAN HUIS; VAN LOON, 2015).

In poultry nutrition, the supply of essential amino acids to fast-growing poultry strains is a key factor. For this reason, diets based on soy meal as the main source of protein, are provided along with fishmeal to eliminate any aminoacidic deficiency of plant proteins (AGAZZI et al., 2016). In contrast, BSFL can be used to provide protein, macro and micronutrients as minerals, eliminating the need for mineral supplementation in poultry diets (DIERENFELD; KING, 2008).

In this context, what makes BSFL an attractive alternative food ingredient for monogastrics, is its nutritional composition, especially with regard to its profile ofessential amino acids(Methionine: 0.7% to 0.9%;ValineKeywords : 2.3% to 2.8%; Lysine: 2.3% to 2.6%; Arginine: 1.8% to 2.0%), crude protein content (≤53%), crude fat content (≤58%) and calcium content (≤7%) (EWALD et al., 2020b; Ruhnke et al., 2018; SPRANGHERS et al., 2018).

As already reported, the meal of black soldier fly larvae has a rich content of proteins and fats, which reinforces the potential of its use in animal feed. The chemical composition of insects can be affected by their diet and their stage of development (LIU et al., 2017). The dry matter and crude protein content varied between 33 and 36% and 38 and 46%, respectively, while the total fatty acid content was not affected (ABD EL-HACK et al., 2020).

With regard to crude protein (CP) contents in the larvae, an increase was observed soon after hatching and then a gradual decrease from 4 to 12 days of larval development, with a minimum concentration of 38% of CP in the larval stage followed by an additional increase of 39.2% in mature larvae on day 14. In the later stages of development, there was a steady increase in CP content to reach a concentration of 46.2% CP in the initial pupal stage. In the postmortem adult stage, the highest level of CP (57.6%) was found (LIU et al., 2017).

Based on the lowest level of CP measured in BSF (36%) by Barroso et al., (2014) and considering only the level of bruna protein, the bran of BSF larvae presented CP content similar or slightly higher than the vegetable protein sources (flaxseed flour, sunflower bran, cotton bran, lupin, wheat distillery grains or beans) (SAUVANT; PEREZ; TRAN, 2004).

Currently, the diet of birds is formulated on the basis of plant protein sources. Cereal protein is the main component of diets around the world. Added to this, lysine, methionine and threonine are the main limiting essential amino acids in cereal-based diets for pigs and poultry. Overall, insects have high levels of these essential amino acids (VAN HUIS, 2013b) and have a better amino acid profile compared to that of soy flour and most common conventional protein sources (TRAN et al., 2015).

Corn gluten bran (60%) is one of the conventional sources of protein in poultry feed. The content of essential amino acids in BSF larval flour is overall better than the content in corn gluten flour (60%); they are similar in valine, while BSF larvae have higher levels of lysine and arginine and lower levels of methionine, threonine and isoleucine (SPRANGHERS et al., 2018).

However, the essential amino acids most represented in BSF larval flour are leucine and lysine (DE MARCO et al., 2015). The amino acid profile in the BSF seems to be related to the age of the larvae, since the highest level was expressed mainly in the early stages of larval development (4th to 6th day), then this level gradually decreased, until the stage of larval maturation, followed by a stable phase in a final stage of the BSF life cycles, as pre-pupa and pupa. However, in dry matter (DM), the adult stage of the larvae was characterized by the highest amino acid content (g/kg) (LIU et al., 2017).

Previous research found that the crude fat content was 4.8% one day after larval stage hatching, followed by an increase over the course of progress in larval development until it reached its maximum level of 28.4% in 14 days (MCGUCKIN et al., 2011).

Liu et al. (2017), estimated the content of minerals and vitamins in feed for chickens containing BSF in commercial phases (mature larvae on the 14th day and initial pre-pupa). Their results showed high vitamin E content in both commercial phases. However, the concentration of vitamin E during the initial prepupa (3.26 mg/100 g), was lower than in the mature larval stage (6.68 mg/100 g). They also reported that most of the micronutrients were found in the later stages of larval development. The pre-pupal stage presented higher content of some minerals compared to the mature larval stages, such as phosphorus and calcium. The results showed that in the initial phase of the pre-pupa, the phosphorus content (620 mg/100 g) was almost double that of mature larvae on the 14th day (350 mg/100 g), while the content of some other minerals – sodium, iron and zinc – was higher in the mature larval stage on the 14th day.

In relation to chitin, the black soldier fly represents an effective way to convert waste into a precious source of nutrients: proteins, lipids and chitin. Chitin (the main component of the arthropod exoskeleton), chitosan (produced by the deacetylation of chitin) and chitooligosaccharides (degraded products of chitosan or chitin) have received great attention due to their great biological and economic values (GORTARI; HOURS, 2013; LEE et al., 2008; LIAQAT; ELTEM, 2018; MUZZARELLI, 2010). Chitin and its derivatives have several applications: food, cosmetics, pharmaceuticals, textile industries, wastewater treatment and agriculture (CALIGIANI et al., 2019).

Recent studies have shown that chitin and its derivatives have an effect on activation of innate immune cells and generation of cytokine and chemokine (LEE et al., 2008). In addition, in light of the potential use of chitin as a dietary supplement, several studies have reported other biological effects of chitin, such as antibacterial activity (BENHABILES et al., 2012), antifungal activity (OLIVEIRA et al., 2008) and antiviral activity against various types of bacteria, fungi, and viruses (CHEUNG et al., 2014).

6 POTENTIAL INCLUSION OF THE BLACK SOLDIER FLY (BSF) IN THE NUTRITION OF PRODUCTION BIRDS

Insects can be an interesting alternative protein, in particular for birds, because in addition to the nutritive role, in natural behavior, birds have the habit of seeking and eating insects throughout their lives (BOVERA et al., 2015). Recent studies have addressed the feasibility of using insect meal in poultry feed under the productive performance (BENZERTIHA et al., 2020; BIASATO et al., 2016; BOVERA et al., 2015; IACONISI et al., 2017), egg production and blood profile of commercial layers (MARONO et al., 2017; MWANIKI; NEIJAT; KIARIE, 2018), nutrient digestibility (BARRAGAN-FONSECA; DICKE; VAN LOON, 2017) and intestinal morphological evaluation and histological features (BIASATO et al., 2016).

It has been shown that the larvae of the black soldier fly or ***Hermetia illucens*** or BSF (Black Soldier Fly) in its integral form can replace up to 15% of the conventional feed ingredients in chicken diets, reducing the cost of feed by 19% when compared to diets based onsoyand fishmeal from Kenya, indicating that BSFL may already be a cheaper ingredient option, with no adverse effects on broiler production parameters in some countries (ONSONGO et al., 2018). Other studies have used BSFL in duck and layer diets with no obvious harmful effects (DABBOU et al., 2018; DE MARCO et al., 2015; Gariglio et al., 2019; RUHNKE et al., 2018).

Makkar et al. (2014) found that the black soldier fly as a substitute for soybean meal resulted in similar weight gain and lower food intake than the control diets, indicating an improvement in feed conversion. On the other hand, Dabbou et al. (2018), verified higher feed consumption and live weight of broilers, who consumed diets containing 15% black soldier fly flour, these results were justified by the authors, due to the greater palatability of the rations when they contained this ingredient.

In another study, it was reported that chickens fed an initial BSF-based diet had daily gain and body weight at 10 days of age, approximately similar to those fed a fishmeal control diet (24.6 vs. 24.5 g/day, 286 vs. 285 g, respectively) (PRETORIUS, 2011). These results were consistent with other studies that did not indicate any differences in daily gain or final weight during the growth phase in beef quail fed a control diet or BSF larval flour diet (CULLERE et al., 2016) or in ducks fed up to 9% of BSF larvae flour in the diet (GARIGLIO et al., 2019).

Linear and quadratic responses were found in body weight and average daily gain during the initial and growth periods due to the inclusion of BSF in the diets of broilers, while the average daily gain decreased linearly during the finishing phase, which can be attributed to some negative effects of the diet of BSF larvae feed on intestinal morphology when administered at a high level (10%) (DABBOU et al., 2020). Nevertheless Borrelli et al. (2021) reported that complete replacement of soybean meal by BSF larval meal in laying hens reduced their body weight (2.09 vs. 1.89 kg, respectively) after a feeding period of 21 weeks.

Another study estimated the total apparent digestibility of crude protein, ether extract and crude energy of BSF larval bran for broilers. The results showed 51% for crude protein digestibility, 99% for ether extract, 69% for crude energy, 53% for dry matter and 66% for organic matter (DE MARCO et al., 2015). These results show that BSF larval bran is a promising alternative as a food in poultry diets.

In contrast, Cullere et al. (2016) examined a partial replacement of soybean meal and soybean oil with two levels of fat-free BSF larval meal (10% and 15%) in the quail diet (10-28 days of age). The apparent digestibility values of crude protein (45.1, 42.9 and 34.0), starch (93.9, 95.7 and 95.7), dry matter (54.0, 58.9 and 55.2), organic matter (58.4, 62.9 and 59.1) and energy (62.0, 65.3 and 63.1) for the control diets, 10% BSF and 15% BSF, respectively, showed no statistical differences between the groups, while the digestibility of the ether extract was lower in the group with inclusion level of 10% BSF compared to the control and 15% BSF. Although the crude fat content in the diet of 15% BSF was the lowest (45.5 g/kg feed) compared to 10% BSF and control diet (51.5 and 61.4 g/kg feed, respectively), the apparent digestibility of the 15% BSF ether extract was significantly higher than those of 10% BSF (89.6 g/kg vs. 82.5), but similar to the control (92.9 g/kg).

This reduction in protein digestibility, which has been reported by many studies and ranged from 8 to 11 percent, may have been due to the presence of protein-cross-linked chitin (CULLERE et al., 2016b; DE MARCO et al., 2015; KOH; IWAMAE, 2013; SEALEY et al., 2011). The chitin content of BSF larvae is approximately 5.41% (FINKE, 2013) and 8.72% for larvae in the pre-pupae phase (DIENER; ZURBRÜGG; Tockner, 2009). However, the average in partially defatted BSF larval flour is 5%, while in highly defatted larvae it is 6.9% of DM (SCHIAVONE et al., 2017). For this reason, when soy or fishmeal protein is replaced by BSF prepupae at partial or total levels, attention should be paid to the balance of dietary amino acids, the ideal amino acid profile for poultry, and reliable digestibility coefficients (SEALEY et al., 2011).

Regarding defatted BSF larval meal, 32-day-old chickens were fed a corn- and soybean-based diet supplemented with 250 g/kg of partially or highly defatted BSF larval meal to estimate apparent digestibility. The feeding test lasted 4 consecutive days after 6 days of adaptation. The apparent digestibility was 62, 98, 61, 63 and 69% for crude protein, ether extract, crude energy, dry matter and organic matter, respectively, in the bran of partially defatted BSF larvae, while for the highly defatted BSF larvae, the value showed 62, 93, 50, 59 and 64% for crude protein, ether extract, crude energy, dry matter and organic matter, respectively (SCHIAVONE et al., 2017).

A significant reduction in the apparent ileal digestibility of dry matter, organic matter and crude protein was found in layers fed complete replacement of soybean meal with defatted BSF larval meal over 21 weeks (3.76, 4.17 and 13.57%, respectively), compared to control birds, while a 5.60% reduction was observed in the digestibility of the ether extract (CUTRIGNELLI et al., 2018). This reduction in digestibility in the study was associated with lower feed intake found in the group that received the treatment containing BSF.

In recent investigations, Kim et al. (2020) tested the replacement of coconut and corn oils with LBSF oil (50 g/kg) for broilers for 30 days and found better CA in diets with coconut oil and LBSF, as well as higher ileal weight/length ratio at 30 days of age using LBSF oil and higher lauric and myristic fatty acid content of abdominal fat (coconut oil and of LBSF), lower content of polyunsaturated fatty acids and increased total antioxidant capacity.

Also in current works, Sypniewski et al. (2020) evaluated the partial x total replacement of soybean oil by fat from BSF (commercially extracted) applied in turkey diets at 7 days of age. The authors observed that the use of fat from BSF did not affect the productive performance, digestibility and morphology of the gastrointestinal tract of birds, however, they observed a reduction in trypsin and pathogenic bacteria (***Enterobacteriaceae sp***.) in the group that received total replacement of soybean oil by insect fat.

In addition to its obvious nutritional potential in diets, BSFL may also offer health benefits of broilers. Some of the potential health benefits come fromlauric acid(C12: 0), which constitutes up to 64% of the total composition ofsaturated fatty acidsof the BSFL (ABD EL-HACK et al., 2020).Fortuoso et al (2019) as well as Londok and Rompis (2019) evaluated the potential benefits of including lauric acid in diets for broilers at 0.03% and 2.6%, respectively, and found a significant reduction in***Escherichia coli***and in total bacterial counts in theexcreta, improving the intestinal health as well as the performance of chickens.

Similarly, an in vitro study reported that BSFL microcompounds can reduce the growth of a large number of harmful microorganisms, including***Staphylococcus aureus*** gram-positive,***S. aureus*** resistant to*methicillin*and***Pseudomonas aeruginosa***gram-negative. These findings suggest that the active microorganisms identified in the larval extract acted as antimicrobials against these microorganisms (PARK, KWAN-HO et al., 2014).

Chitin, as part of the BSFL exoskeleton, represents a significant constituent and has also been reported to have immunomodulatory effects in mammals on the innate and adaptive immune system (ELIEH ALI KOMI; SHARMA; DELA CRUZ, 2018). Recent studies have shown that chitin and its derivatives have a potentiating effect on the responses of each innate and adaptive immune system, including recruitment and activation of innate immune cells and generation of cytokine and chemokine (LEE et al., 2008; MUZZARELLI et al., 2010).

In addition, in view of the potential use of chitin as a dietary supplement, several studies have reported other biological effects of chitin, such as antibacterial activity (BARROSO et al., 2014; BENHABILES et al., 2012; CHOI et al., 2001; LAOKULDILOK et al., 2017; MATEOS-APARICIO; MENGÍBAR; HERAS, 2016; SANCHEZ et al., 2017)Antifungal (MEI et al., 2015; OLIVEIRA et al., 2008; RAHMAN et al., 2015) and antiviral (ARTAN et al., 2010; Cheung et al., 2014; CHIRKOV, 2002; NIU et al., 2018) against various types of bacteria, fungi and viruses. In addition, the importance of chitin and its derivatives as dietary supplements in poultry and swine nutrition has been reviewed and investigated in several studies (GEREZ et al., 2019; HU et al., 2018; NOURI, 2019).

Chitinase may act as a protease-resistant digestive enzyme that dissociates chitin in the chicken gut, indicating that chitinase can be supplemented in poultry diets, especially insect-fortified diets, to improve its nutritional value (TABATA et al., 2017). The mRNA level of chicken chitinase was extremely high and was the second most abundantly expressed transcript in the glandular stomach, exceeded only by pepsinogen A. These findings showed the importance of chitinase in the digestion of diets containing chitin (TABATA et al., 2017).

Chicken chitinase has robust activity at pH 2.0–2.3 (SUZUKI et al., 2002; TABATA et al., 2017) and, therefore, its activity is high in the proventriculus, low in the duodenum, and insignificant in the jejunum and ileum (KOH; IWAMAE, 2013). Previous findings also reported the same finding that the functional significance of chitinase in the intestinal lumen is doubtful (RAMOS-ELORDUY et al., 2002). However, Tabata et al. (2017) incubated shells of flour larvae in the stomach extract of white leghorn chicken for 1 or 16 h and reported that the insect's chitin was degraded to $(GlcNAc)_2$ by endogenous chitinase in the pH conditions of the stomach and intestine.

Total antioxidant status in plasma, hemoglobin content and glutathione peroxidase activity (GPx, EC 1.11.1.9) in blood were evaluated in male broilers fed with BSF larval flour in the diet. Both total antioxidant status and GPx activity indicated a linear increase response to increased inclusion of BSF larval bran in the diet by up to 15% (DABBOU et al., 2019). However, no significant effects on the levels of antioxidant enzymes in blood and plasma (GPx and TAS) were observed due to the inclusion levels of BSF larval flours in Muscovy duck diets (GARIGLIO et al., 2019).

On the other hand, dietary inclusion levels of BSF larval bran modulated the plasma oxidative metabolites malondialdehyde (MDA) and nitrotyrosine, in addition to indicating a linear decrease in their values as a healthy indicator of antioxidant status (GARIGLIO et al., 2019). The results mentioned above indicate that the inclusion of BSF in poultry feed improves its antioxidant status, however, further investigations are needed to clarify this point.

With regard to histological characteristics, unfortunately, there are no more studies related to these points in the literature. However, a recent study showed that no significant effect was found on hematochemical or histological characteristics due to BSF larval meal in the diet of male broilers (DABBOU et al., 2019) or in ducks (GARIGLIO et al., 2019).

Insect flours can also influence the meat quality of chickens, Altmann et al. (2018) found more stable pH levels in fresh breast fillet up to 7 days after packaging, compared to the breast fillet of the control group, when welded fly flour was included, assuming that this inclusion also delayed the shelf life of the product.

Data from a study by Cullere et al. (2016) showed that the cooked breast of quails fed a 10% BSF diet was the heaviest and softest compared to 15% BSF and control diets, while no significant effect was observed on fresh breast meat yield. In addition, no significant effect was observed on crude protein content or total essential amino acid composition of breast muscle in broilers fed housefly larval meal for 35 days. However, the values were higher for chickens fed a larval meal-based diet than those fed a soy-based control diet.

In addition, a significantly higher content of lysine and tryptophan and total amino acids were recorded in the larval flour group than in the control group (HWANGBO et al., 2009).

Moula et al (2018), estimated the protein content, fatty acid profile, ash percentages, and omega 6/omega 3 ratio in poultry meat fed a diet supplemented with 8% fresh BSF larval meal. No significant differences were observed between larvae-fed and control chickens in relation to breast color (MOULA; DETILLEUX, 2019) and thigh muscle or pH (PRETORIUS et al., 2011). The approximate meat composition, cholesterol content and oxidative state were not influenced by the administration of BSF (CULLERE et al., 2019).

Increasing the inclusion of defatted BSF in the diet by up to 15% led to an increase in the breast meat content of total saturated fatty acids, total monounsaturated fatty acids, and polyunsaturated fatty acid (PUFA), while a significant reduction was found in polyunsaturated fatty acids. These observations reflected differences in the dietary content of these nutrients. However, this finding indicates that increasing the inclusion of BSF in the diet may decrease the healthiness of poultry meat (CULLERE et al., 2019).

Similarly, the fatty acid profile of broiler breast was highly influenced by the level of fat inclusion in BSF larvae. With the increase in the rate of fat inclusion in BSF larvae, the proportion of saturated fatty acid increased to the detriment of the polyunsaturated fatty acid (PUFA) fraction. In addition, the ratio of n-6/n-3 increased (CULLERE et al., 2019; SCHIAVONE et al., 2017).

On the other hand, the biological value of meat protein was increased, presenting higher levels of aspartate, glutamate, alanine, serine, tyrosine and threonine due to the diet being supplemented with 15% of defatted BSF (CULLERE et al., 2019). The same dietary inclusion (15%) of BSF larval bran resulted in higher concentrations of Ca and lower K in breast meat than the control group, being a reflection of the nutrient content of the diet (CULLERE et al., 2019).

The breast meat obtained from chickens fed with 15% of FSB larvae bran presented a higher redness index (a *), while the birds fed with 5% and 10% presented intermediate values in relation to the control. These findings may be the result of pigments derived from larval flour. On the contrary, a linear decrease was found for the yellowing value (b *) with the increase in the bran content of BSF larvae. This result may have been due to the low gluten content of corn in BSF diets (SCHIAVONE et al., 2019).

7 FINAL CONSIDERATIONS

It is remarkable and indisputable that the Black Soldier Fly (BSF) is a promising food source for birds with a high nutritional value, especially in essential amino acids, protein and fats, as well as being able to promote the degradation of a number of materials of organic origin, converting waste into an important biomass for animal feed.

In place of fish meal and soybean meal (the main protein ingredients incorporated in the feed of monogastric animals), the use of BSF could result in excellent indicators of weight gain for birds, as well as improved feed conversion, greater health promotion, inhibition of the development of harmful bacteria and a possible improvement in the antioxidant status of these animals.

However, even with the benefits of the use of BSF in the feeding of monogastric animals, the current production cost of these insects in the country is still high and relevant when compared to other sources, so-called conventional (fish meal and soybean meal). Other challenges such as the standardization of the bromatological compositions of the flours from these insects, increased production, as well as a cultural change in the Western way of seeing these organisms, are issues to be made viable.

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