CHAPTER 3

USE OF INSECTS AND BY-PRODUCTS IN QUAIL FEEDING

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ABSTRACT: Protein is essential for the growth and development of poultry and plays a crucial role in tissue maintenance and repair. However, the use of animal-derived protein meals faces significant challenges, such as high costs and risks of disease transmission. In this context, the search for safer and more accessible alternatives is essential. Insects have emerged as a promising solution due to their high nutritional value, low environmental impact and ability to transform waste into rich food. In addition, insect production does not compete with food resources and has an amino acid profile comparable to or superior to that of soybean meal. This study explores the inclusion of insects in quail diets, highlighting their nutritional benefits and their potential to promote sustainable and ecologically responsible feeding practices.
KEYWORDS: Quails, Insects, Animal nutrition, Alternative protein, Sustainability.

USO DE INSETOS E SEUS SUBPRODUTOS NA ALIMENTAÇÃO DE CODORNAS

RESUMO: A proteína é fundamental para o crescimento e desenvolvimento das aves, desempenhando um papel crucial na manutenção e reparação dos tecidos. No entanto, o uso de farinhas proteicas de origem animal enfrenta desafios significativos, como altos custos e riscos de transmissão de doenças. Nesse contexto, a busca por alternativas mais seguras e acessíveis é essencial. Insetos surgem como uma solução promissora, devido ao seu alto valor nutricional, baixo impacto ambiental e capacidade de transformar resíduos em alimentos

ricos. Além disso, a produção de insetos não compete com recursos alimentares e apresenta um perfil aminoacídico comparável ou superior ao de farelo de soja. Este estudo visa explorar a inclusão de insetos na dieta de codornas, destacando seus benefícios nutricionais e seu potencial para promover práticas alimentares sustentáveis e ecologicamente responsáveis.
PALAVRAS-CHAVE: Codornas, Insetos, Nutrição animal, Proteína alternativa, Sustentabilidade.

INTRODUCTION

Protein is an essential nutrient in poultry diets and plays a crucial role in tissue maintenance and repair, which is essential for proper growth and development (Hatab et al., 2020). However, the high cost of animal protein meals and their potential to transmit diseases have imposed new restrictions on global poultry production (Womeni et al., 2012; Hatab et al., 2020). Therefore, it is vital to find safe, accessible and low-cost feed sources to replace traditional proteins.

Insects have emerged as a viable alternative due to their high nutritional value (rich in energy, proteins, amino acids and fatty acids) and low environmental impact (Bovera et al., 2016; Hatab et al., 2020; Cufadar et al., 2021).

Large-scale insect production for animal feed is advantageous because it does not compete with food resources and land use. In addition, insects can transform industrial by-products and polluting waste into food with high nutritional content, promoting nutrient recycling (Prates et al., 2023). They act as immunomodulators and have beneficial effects on the microbiota of the digestive system. Protein production per hectare is higher than grain production, with an amino acid profile similar or superior to soybean meal and animal meal, which can reduce the final cost of the feed (Oliveira et al., 2020; Prates et al., 2023).

In this context, the aim of this study was to explore the feasibility and potential nutritional benefits of including insects and their co-products in quail diets. Emphasizing the essential role that this approach can play in promoting a healthy and ecologically responsible diet for quails, in line with the growing demands for sustainable food practices.

USE OF INSECTS IN ANIMAL FEEDING

The world's population is continually growing, which raises essential questions about our future capacity to produce and provide adequate and nutritious food. There is an estimate of a necessary 70% increase in global food production by 2050, compared to 2009 (FAO, 2009), to meet the additional need for food for human and animal populations, as real challenges have arisen for food production professionals, researchers and politicians will face (Henchion et al., 2017). The growing demand for animal proteins negatively impacts the environment because of rising greenhouse gas emissions and increased water, energy, and land use (Ishangulyyev et al., 2019). Fears about global food security have arisen from the loss and waste of food throughout the supply chain, which accounts for around one-third of all food produced for human consumption (1.3 billion tons of food) and has significant negative economic and environmental impacts (Roma et al., 2020).

Within research focused on prospecting alternative sources of protein in human and animal nutrition, as well as in food waste, edible insects are increasingly presenting themselves as valid alternatives for proteins of animal origin (Borrello et al., 2016) and in the treatment of waste (Madau et al., 2020). Insects efficiently bio-convert food or by-products into proteins of high biological value (Van Zanten et al., 2015), and depending on the species or processing method, insects and their co-products can contain an average amount of protein (on a dry matter basis, %MS) ranging from 50% to 82%, as well as being rich in nutrients such as calcium, iron, and zinc (Rumpold & Schlüter, 2013). Insects are a source of food with a low environmental impact due, among other things, to the limited need for arable land and water compared to traditional livestock farming (Banjo et al., 2006) and the low ecological cost (low greenhouse gas and carbon dioxide emissions) (Fasakin et al., 2003).

Entomoculture has remained an almost unknown practice until recently. Insects are typically captured in wild conditions in Africa and Asia (Lorenzo et al., 2020). Land use for agriculture, desertification, and urbanization has progressively reduced the capture of wild insects (Lorenzo et al., 2020). At the same time, the rearing of edible insects has begun to emerge as a viable and sustainable alternative to wild capture (Raheem et al., 2019). In this way, insect farming is also attracting growing interest in countries that are not traditionally involved in entomophagy, such as Europe and the United States of America, where insect-based co-products are increasingly commercialized (Nadeau et al., 2015). Insect farming, also known as entomoculture, combines economic benefits with the production of food and feed ingredients that can beneficially affect the diet of the population in both developed and developing countries (Nadeau et al., 2015). It has been highlighted in scientific literature that insects have a nutrient composition suitable for inclusion in ruminant feed (although their use is still prohibited in Brazil for these animals) and in aquaculture production systems (rearing fish, crustaceans and other aquatic animals), pigs, poultry, dogs, and cats (Kerensa et al., 2021).

Consumption of poultry products is expected to increase in the coming years; therefore, there is a significant need for new feed ingredients that can sustainably facilitate intensive poultry production (Yuan and Moriguichi, 2006). Insects are high-quality protein sources rich in essential amino acids and lipids. The protein content of insect meal can vary significantly, ranging from almost 40% to 60% (Jabbour et al., 2019). Variation in nutrient content can also be influenced by factors such as feeding habits, including the types of food consumed in the ecological niche (preferably natural feeding patterns, and how these aspects affect the nutrient content and overall nutritional profiles of insects), developmental stage, and prevailing environmental conditions, leading to very different nutritional profiles, even among phylogenetically related insect taxa (Gallaud and Laperche, 2016).

The protein composition of insect dry matter varies significantly between different insect species, ranging from 35% in termites to 61% in crickets and grasshoppers, with some species exhibiting even higher protein contents of up to 77% (Rumpold and Schlüter, 2013). Most edible insect species exhibit adequate levels of essential amino acids, including tyrosine, tryptophan, phenylalanine, lysine, and threonine, in line with recommended dietary requirements. Edible insect species possess sufficient levels of these important amino acids, which may be beneficial for commercial poultry nutrition (El-Sabrout et al., 2023). Insects mainly store carbohydrates in two forms: chitin and glycogen. Chitin, the main component of their exoskeleton, is a polymer of N-acetyl-D-glucosamine. In contrast, insect muscle cells store glycogen as an energy source (Ojha et al., 2021). Edible insects contain varying amounts of carbohydrates (Tenebrio mealworm larvae: 14-18%; crickets: 10-20%; grasshoppers: 11-21%; silkworm pupae: 10-20%; ants: 2-15%). However, specific carbohydrate content may depend on factors such as insect species, diet and stage of development (Mlček et al., 2014).

he literature shows that insects contain variables ranging from 2% to 62%, with large amounts of unsaturated FAs constituting up to 75% of the total fatty acid content. Although the vitamin content of insects is not particularly high, they do contain notable amounts of vitamins A, C, D, and E (Zamudio-Flores et al., 2019). Insects such as crickets and termites have varied mineral contents, with some being rich in magnesium, zinc, and copper, while others such as grasshoppers and mealworms have higher levels of copper, magnesium, manganese and zinc than beef. However, insects are generally low in sodium, calcium and potassium (Mwangi et al., 2018). The substantial amounts of amino acids, mineral substances and vitamins make insect meal a potential competitor to conventional protein sources such as fishmeal and soy.

As insects are a source of food for many species of birds, their introduction into poultry farming is being intensively studied by researchers around the world. These studies covered different types of diets, species and stages of insect development. Furthermore, these studies focused on both broilers and laying hens. Recently, tests with broilers have been carried out using diets of different insect species, such as BSF (*H. illucens*), houseflies, silkworms (*Bombyx mori)* and giant tenebrio (*Zophobas morio*), testing isoprotein and isoenergetic diets (Murawska et al., 2021).

Murawska et al. (2021) studied the inclusion of BSF in broiler diets, tested high levels of dietary inclusion (starter: 20-30 and 40%; grower: 20-25 and 35%; finisher: 10-20 and 30%) and reported lower growth performance (CP, feed consumption and daily weight gain (DWG)) in the insect treatments than in the control, except for the DWG of the 10% group during the finisher phase. Regarding FC, no differences were observed between the control and the two diets with the lowest inclusion levels, while the dietary treatment with the highest insect content produced the lowest value (Murawska et al., 2021).

SPECIES USED IN ANIMAL FEED

The use of insects in animal feed is a sustainable and efficient alternative to meet the growing demands of the farming industry. This practice, known as entomophagy, involves including insects in the diet of farmed animals such as poultry, fish, and pigs, providing both environmental and nutritional benefits (Gałęcki et al., 2021).

Edible insects are known to have significant levels of protein, fat, vitamins, fiber, and minerals, although these levels can vary between different species (Kouřimská and Adámková, 2016). Considering the concern for sustainability, exploring alternative food sources, such as insects, could help reduce dependence on ingredients such as fishmeal/oil and soy, which are considered less sustainable for feed production. However, it is essential to carry out a detailed analysis of the nutritional composition of each insect species, taking into account factors such as life stage, rearing conditions and specific diet, to ensure that they meet the nutritional requirements of the species of interest. Only in this way can it be possible to formulate balanced rations that promote the best performance and health of the animals, regardless of their species (Nascimento et al., 2020).

It is important to note that certain types of insects not only represent an excellent source of nutrients but also have antimicrobial compounds (Li et al., 2023). These nutrients play a crucial role in enhancing the animals' immune response, and even help to prolong the shelf life of feed incorporating insect meal.

The use of edible insects in the feeding of farm animals is a scientific area that is still in its infancy compared with research dedicated to the production of these animals (Gomes et al., 2023). The significant number of studies in this field has provided promising results. Despite this, the current production of edible insects does not yet fully meet the growing demand for animal protein on the market. However, it is already feasible to reap the benefits of edible insects by integrating them as supplements at specific stages of the production process. It is crucial for researchers and producers pay due attention to the particularities of each location, situation and production sector in order to optimize this practice (Nascimento et al., 2020).

Among the categories of edible insects, 80% are associated with the orders Coleoptera (beetles), Hymenoptera (ants, bees), Orthoptera (grasshoppers and crickets), and Lepidoptera (caterpillars). The remaining 20% covers orders such as Hemiptera (cicadas, aphids), Isoptera (termites), Diptera (flies) and others (Lavalette, 2013). However, comprehensive research into these orders is limited due to the peculiar characteristics of certain species, which make them more promising than others for the current application of entomoculture in animal feed. Although thousands of species of food insects are cataloged globally, only a few are commercially produced in captivity for animal feed, including crickets, beetles, cockroaches and flies (Nascimento et al., 2020).

Coleoptera, Diptera, and Lepidoptera are predominantly consumed during the larval stage, while the other species are generally eaten in the adult stage (Yi et al., 2013). In terms of consumption, the adult stage is initially more convenient although the larval stage may have a higher nutritional profile. In addition to the larval and adult stages, some species go through additional stages, such as pre-pupa and pupa. For example, during the pre-pupal stage, the black soldier fly demonstrates two notable advantages: reduced risk of pathogenicity due to the emptying of the digestive tract and a migration behavior adapted to facilitate self-collection in industrial-scale systems (Danieli et al., 2019).

Tenebrio molitor

Tenebrio molitor, popularly known as the "flour maggot", is a member of the *Tenebrionidae* family, also known as the "dark beetles", which is the fifth largest family in the Coleoptera order, with more than 14,000 species distributed globally. Like many other members of this family, *T. molitor* is a nocturnal species that prefers dark and humid environments, such as grain elevators, bird cages, chicken nests, grain silos, feed sacks and food storage facilities (Gkinali et al., 2022). The specimens varied in size, with females reaching between 10 and 18 mm, while males usually measure between 10 and 15 mm (Figure 1).

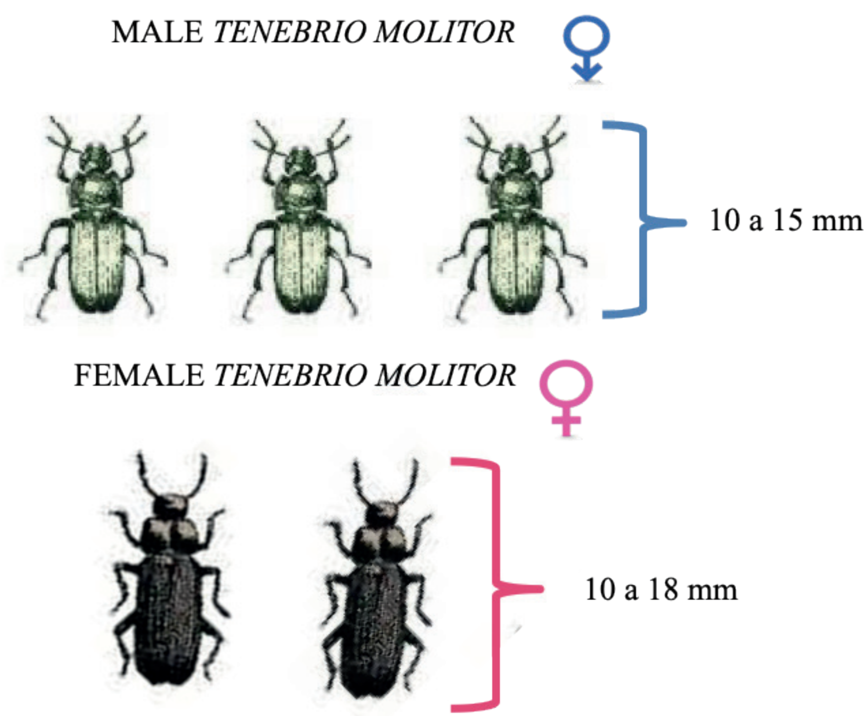

Figure 1: Male and Female *Tenebrio molitor*

The life cycle of the tenebrio is complete and variable, lasting from 280 to 630 days and consisting of four distinct metamorphic stages (Figure 2): egg, larva, pupa and adult (Finke, 2002; Yu et al., 2021). Each female had the capacity to lay approximately 500 eggs, which are ovoid and elongated in shape, coated with a sticky substance that adheres the eggs to the substrate. The larvae hatch in a period of 10–12 days, measuring around 3 mm in length and displaying a whitish color. In a few days, the larvae produce a chitinous exoskeleton with a yellowish hue. The complete larval stage is 2–3.5 cm long and weighs between 130 and 160 mg, lasting 3 to 4 months. The pupal stage lasts approximately 7–9 days, is creamy white in color and measures 1.2 to 1.8 cm in length. The adult resulting from the larval stage of flour lives for around 3 to 4 months (Siemianowska et al. 2013; Makkar et al. 2014; Alves et al., 2016).

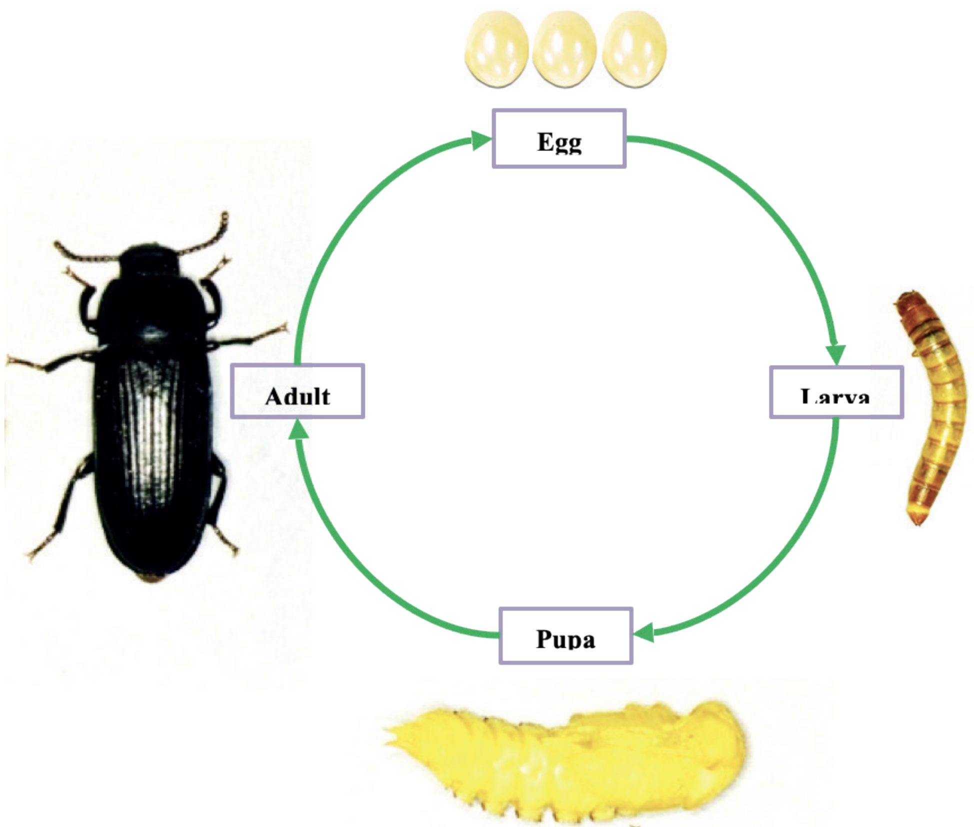

Figure 2. Life cycle of *the Tenebrio molitor*

Tenebrio molitor (*T. molitor*) larvae are considered good sources of protein for non-ruminant animals. High protein content and amino acid profile in quantity and quality. The crude protein (CP) content of *T. molitor* larvae averaged 52.4% and ranges from 47.0% to 60.2%, which is higher than that found in soybean meal (49.4%) and lower than that found in fishmeal (67.5%). *T. molitor* larvae contain an average of 30.8% crude fat, which can vary depending on the processing method used to extract it. The crude fat content of *T. molitor* larvae were higher than those found in soybean meal (1.4%) and fishmeal (10.4%). However, the average crude ash content (4.2%) of *T. molitor* larvae is lower than that of soybean meal (7.2%) and fishmeal (17.2%) (Hong et al., 2020).

The fiber content of *T. molitor* larvae originates from their cuticles. The crude fiber content of *T. molitor* larvae was 7.43% and ranges from 4.19% to 22.35%. The average crude fiber content of *T. molitor* larvae was similar to that found in soybean meal (7.43%) and higher than that found in fish meal (0.26%) (Hong et al., 2020).

The amino acid profile of *T. molitor* larvae revealed that leucine, valine, and lysine were the most prevalent essential amino acids, while Histidine, Methionine and Tryptophan are the least abundant. Lysine's proportion varies from 1.58% to 5.76%, and that of Methionine varies from 0.52% to 2.20% in the larvae. Additionally, Threonine levels vary from 1.57% to 4.29%, and Tryptophan levels vary from 0.02% to 1.86%. *T. molitor* larvae exhibit higher levels of lysine, methionine, threonine, tryptophan, valine, and isoleucine than soybean meal. Although the levels of lysine, methionine, and threonine are lower than those of fishmeal, the contents of Tryptophan, Valine and Isoleucine exceed those of fishmeal (Hong et al., 2020). Table 1 presents the nutritional composition of *Tenebrio molitor* larvae with potential for use in animal feed.

Items	Values
	Tenebrio molitor larvae
Crude protein, g/kg	490,2
Ether extract, g/kg	335,4
Gross energy, kcal/kg	7188,6
NDF, g/kg	71,8
FDA, g/kg	64,0
Ash, g/kg	36,8
Macrominerals (g/kg)	
Total phosphorus	8,56
Potassium	8,39
Sodium	1,39
Total calcium	0,44
Magnesium	2,30
Microminerals (mg/kg)	
Iron	48,4
Manganese	15,0
Zinc	189
Copper	18,0

Table 1. Proximal composition and mineral content of *Tenebrio molitor* larvae (based on dry matter).

Source: Adapted from Fialho et al. (2021)

In summary, studies have shown that *Tenebrio molitor* larvae represent a promising and sustainable alternative for feeding poultry, especially quails, due to their high protein content, suitable amino acid profile, and environmental benefits associated with their production (Prates et al., 2023). Morsy et al. (2022) evaluated the replacement of levels of 2.5, 5.0, 7.5 and 10.0% of a basal diet with *Tenebrio molitor* meal. The results indicated that 10% substitution maximized body weight and weight gain and improved the feed conversion ratio. In addition, we observed that the use of *Tenebrio molitor* meal can positively influence the immune status and biochemical parameters of quails. There were improvements in meat quality, carcass weight, and levels of crude protein, methionine, lysine, leucine, isoleucine, arginine, valine, glycine and saturated fatty acids present in the meat. In addition, there was a reduction in the levels of triglycerides and total cholesterol.

The inclusion of mealworm meal along with other alternative ingredients, such as meal derived from olive leaves (*Olea europaea* L.), can improve the body weight of Japanese quails. These benefits were observed when replacing 3% of the standard diet with mealworm meal and 2% with olive meal, without causing negative impacts on carcass yield, edible organs, and biochemical levels such as lipids, serum proteins, creatinine and urea (Ait-Kaki et al., 2021).

When incorporated into the diet at levels of up to 30 g/kg of feed, replacing soybean meal and fishmeal, beneficial effects were observed on body weight, weight gain, feed conversion, breast yield, carcass yield, meat quality, and jejunal morphology (Zadeh et al., 2019). On the other hand, replacing fishmeal exclusively with the same amount (up to 30 g/kg) resulted in an increase in weight gain and a reduction in cholesterol levels and did not interfere with hematological and biochemical indices or the expression of the interferon ɣ (IFN-ɣ) gene, which is associated with infectious and inflammatory processes. This suggests that the state of health was not affected (Zadeh et al., 2020).

In summary, the inclusion of tenébrio meal in the diet of quail is a promising strategy to promote intestinal health, improve feed efficiency and contribute to the overall performance of these birds. However, it is important to consider factors such as meal quality, diet balance, and the specific needs of quails at different life stages in order to optimize the benefits provided by the meal.

Zoophobas morio

Zophobas morio is a member of the extensive family of Tenebrionidae beetles, which includes several species of insects associated with stored products, such as *Tenebrio molitor* and *Alphitobius diaperinus*. Other notable members of this family include the confused flour beetle, *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae), and the red flour beetle, Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) (Rumbos & Athanassiou, 2021).

Although *Z. morio* is classified as a storage insect, it has been identified associated exclusively with wheat flour (Hagstrum and Subramanyam, 2009), suggesting its insignificant relevance as a secondary pest of storage insects. In nature, reports indicate its presence in association with fruit bat guano (feces) and organic waste (Tschinkel and Willson, 1971). Originally from the tropical regions of Central and South America (Marcuzzi, 1984; Tschinkel, 1984; Hagstrum and Subramanyam, 2009), the beetle has also been introduced to various regions of Europe and Asia (Yuan et al., 2012; Fursov and Cherney, 2018; Rumbos & Athanassiou, 2021).

Zophobas morio: Identification, Main Characteristics and Biology

Similar to *Tenebrio molitor*, *Zoophobas morio*'s life cycle is complete and variable, consisting of four distinct metamorphic stages (Figure 3): egg, larva, pupa, and adult stages.

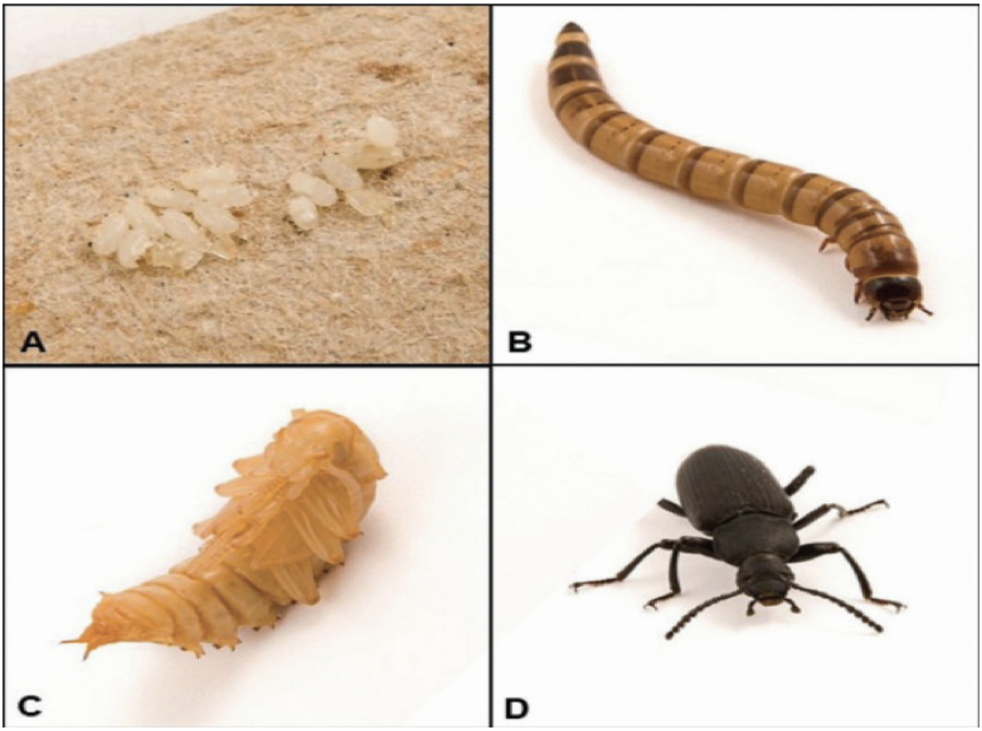

Figure 3: Life stages of *Zophobas morio*: (A) eggs, (B) late-stage larva, (C) pupa (D) adult.

Source: Adapted from Rumbos & Athanassiou, 2021

The eggs of the *Z. morio* species are oval in shape with rounded edges and white in color. They are approximately 1.7 mm long and 0.7 mm wide (Figure 3A) (Fursov and Cherney 2018). Each female has the capacity to lay a significant number of eggs, which can reach up to 2,200 during her lifetime. This number of eggs is inversely related to the maternal age of the female and directly related to the population density of adults (Rumbos & Athanassiou, 2021).

In the larval stage, they are yellow in color with dark brown anterior and posterior extremities (Figure 3B; Fursov and Cherney 2018). Their exoskeleton is cylindrical, highly sclerotized, and narrowed conically from the seventh to the ninth abdominal segment. The maximum length they could reach was 55 mm (Friederich and Volland 2004). Hatching occurs after approximately 8 days at a temperature of 25°C (Kim et al. 2015). One of the most notable peculiarities of this species is that its larvae cannot proceed to the pupal stage under conditions of overpopulation, despite the continuity of the larval moulting process until death (Rumbos & Athanassiou, 2021).

The pupae (Figure 3C) predominantly remain quiescent. However, when tactilely stimulated, they can perform circular movements with their abdominal segments (Ichikawa and Kurauchi 2009, Ichikawa et al. 2012b) or exhibit other physical responses (Ichikawa et al. 2012a, Ichikawa and Sakamoto 2013). These reactions are considered effective defense mechanisms for pupa against predators and cannibalistic behavior by other larvae.

The pupal period lasts 13–15 days at 25°C, varying according to pupal weight (adults emerge more quickly from small pupae) and temperature (adult hatching occurs more quickly at 29°C) (Quennedey et al. 1995). Similar to other tenebrionid species, such as *T. molitor* (Bhattacharya et al. 1970) and *A. diaperinus* (Esquivel et al. 2012), it is possible to easily distinguish the sex of individuals during this life stage. This can be done by observing the presence of two distinct projected pygopodes on the ninth abdominal segment of female pupae, close to the urogomphus, which are absent in male pupae (Fursov and Cherney 2018).

During their adult phase, *Z. morios* reach large proportions, with bodies ranging in length from 38 to 57 mm in length, having an elongated shape and filiform antennae (Figure 3D). The surface of the elytra was marked by nine rows of perforations, each with bristles. The life expectancy of adults can reach up to 6 months (Fursov and Cherney 2018).

Studies on the nutritional profile of *Zophobas morio* larvae have indicated their significant quality as sources of nutrients (Barroso et al., 2014; Bosch et al., 2014; Adámková et al., 2017; Araújo et al., 2019). The larvae were shown to be rich in nitrogen, with their total content varying between 6.2% and 8.6% (Table 2). Reports indicate that larvae have chitin contents of between 3.9% and 6% (Adámková et al., 2017; Shin et al., 2019; Benzertiha et al., 2020; Kulma et al., 2020). Regarding amino acid profile, *Z. morio* larvae have relatively high amounts of all essential amino acids, except methionine (Table 2). In terms of fat content, larvae have a high proportion of lipids, ranging from 35.0% to 43.6% (Table 2), considerably exceeding other insect species that are also considered sources of nutrients (Barroso et al., 2014). Fatty acid analysis revealed that *Z. morio* larvae have high levels of saturated (SFA) and monounsaturated (MUFA) fatty acids, with palmitic acid and oleic acid being the most abundant, respectively (Table 2). Among the polyunsaturated fatty acids (PUFA), omega-6 linoleic acid is abundant in *Z. morio* larvae (Table 2; Barroso et al., 2014). In addition, *Z. morio* larvae contain various minerals (Table 2) and vitamins (Finke, 2002, 2015), as well as high nitrogen and lipid contents.

Centesimal composition	**Larvae**
Dry matter (% as fed)	35,2-42,1
Total nitrogen (% DM)	6,2-8,6
Crude fat (% DM)	35,0-43,6
Ash (% DM)	2,4-8,2
Neutral detergent fiber (NDF) (% DM)	9,3-13,0
Acid detergent fiber (FDA) (% DM)	6,3-6,5
Energy (kcal/100 g DM)	559,2-575,5
Amino acid content (% DM)	
Arginine	2,2-3,5
Histidine	1,4-2,3
Leucine	3,4-4,5
Lysine	2,4-2,9
Isoleucine	2,2-2,4
Phenylalanine	1,6-2,2
Methionine	0,5-1,0
Threonine	1,9-2,0
Tryptophan	0,4-0,5
Valine	2,4-3,4
Alanine	3,4-4,0
Aspartic acid	3,8-4,7
Glycine	2,3-3,0
Serina	2,2-2,7
Proline	2,6-3,7
Cystine	0,4-0,5
Glutamic acid	5,7-6,6
Tyrosine	3,3-3,9
Mineral composition (mg/100g DM)	
Calcium	31,9-70,8
Phosphorus	562,9-564,9
Magnesium	39,2-118,3
Sodium	104,1-112,8
Potassium	750,6-773,0
Chloride	361,1-440,5
Iron	2,3-5,4
Zinc	2,5-8,2
Copper	0,5-1,0
Manganese	0,5-1,0
Fatty acid composition (% of total fatty acids)	
Palmitic (C16:0)	29,1-32,4
Palmitoleic (C16:1)	1,0-3,2

Stearic (C18:0)	6,4-8,8
Oleic (C18:1)	31,1-38,0
Linoleic (C18:2)	15,6-23,4
Saturated (SFA)	38,8-44,6
Monounsaturated (MUFA)	32,1-42,4
Polyunsaturated (PUFA)	15,7-24,0
Omega-6	16,5-24,0

Table 2. Composition of *Zophobas morio* larvae

Source: Adapted from Rumbos & Athanassiou, 2021

Diets containing *Zophobas morio* larvae meal has recently aroused considerable interest among researchers, especially in poultry feed. Benzertiha et al. (2020) evaluated the effects of including small proportions (0.3%) of whole *Z. morio* larvae meal in broiler diets, either added directly to a complete diet or incorporated into calculated diets. The study examined the resulting effects on performance, as well as on characteristics of the birds' immune system. The researchers observed significant improvements in body weight gain and feed consumption. In addition, they identified positive effects on plasma immunoglobulin levels, namely IgY and IgM.

In a similar study, Benzertiha et al. (2019) investigated the effects of adding minimal amounts (0.2% and 0.3%) of *Z. morio* meal to broiler diets. The study assessed apparent ileal digestibility coefficients, pancreatic enzyme activity, short-chain fatty acid concentrations, bacterial enzymes and the composition of the microbiota in the caecal digesta. The results revealed no adverse effects on ileal nutrient digestibility coefficients or pancreatic enzyme activity. The inclusion of whole *Z. morio* flour in the diet improved bird health by reducing concentrations of pathogenic bacteria such as *Bacteroides-Prevotella* and *Clostridium perfringens*. In addition, supplementation with small amounts of *Z. morio* flour (0.2% and 0.3%) stimulated the microbiota of the gastrointestinal tract to produce glycolytic enzymes. This addition showed a prebiotic effect, increasing the relative abundance of probiotic and commensal bacteria, such as Actinobacteria, in the cecal microbiome. These microorganisms protect against infection by pathogenic bacteria (Józefiak et al., 2020; Rumbos & Athanassiou, 2021).

In the same way that adding *Zoophobas morio* (Tenebrio gigante) meal to broiler chicken feed has proved to be a promising strategy, the same principle can be applied to quails, with the aim of promoting the birds' intestinal health. This practice can stimulate the microbiota of the gastrointestinal tract to produce predominantly glycolytic enzymes, resulting in improved feed efficiency and contributing to the productive performance of these animals.

Hermetia illucens (Black soldier fly)

The black soldier fly (*Hermetia illucens*) (Figure 4), also known as the Black Soldier Fly (BSF), inhabits tropical and subtropical regions (Antunes, 2022; Ewusie et al., 2019). Since the 1990s, its breeding has been suggested as an efficient way to manage organic waste, turning it into biomass rich in proteins and fats (Makkar et al., 2014).

The black soldier fly goes through five main stages of its life cycle: egg, larva, pre-pupa, pupa and adults (Figure 4) (Li et al., 2011; Silva & Hesselberg, 2019). The larval and pupal stages were the longest, while the egg and adult stages are shorter. Females lay between 500 and 900 eggs (Julita et al., 2020), which hatch in around four days, although this can vary depending on the season, region, and temperature. During the six larval stages, the larvae vary in size from 1.8 to 20 mm, with mature larvae reaching 20 mm.

Upon emerging, the larvae immediately begin to feed on various types of organic matter, such as animal manure, decaying fruit and vegetables, and food waste, with the rate of consumption increasing significantly after the third instar (Liu et al., 2019). In the 6th instar, the larvae undergo melanization, darkening the cuticle, and turning into prepupae. At this stage, the insect empties its digestive tract and stops feeding, migrating to dry areas to metamorphose into pupae over a period of 7–10 days.

During the pupal stage, which lasts at least 8 days, the larvae do not move or feed, culminating in the emergence of the adult (Silva & Hesselberg, 2019). Adult flies feed only on water, using the fat reserves accumulated during the larval stage. It does not damage crops, pollute the environment, spread disease, or invade homes or restaurants, preferring shaded areas (Liu et al., 2019) for maturing and mating. The reproductive cycle of the adult fly lasts for 5–8 days, after which the female dies shortly after oviposition (Silva & Hesselberg, 2019).

Figure 4: Life cycle of the black soldier fly. Adapted from an Insect School in 2023

The larvae have the ability to rapidly consume between 25 and 500 mg of fresh matter/larva/day, covering a wide variety of decomposing materials, such as decaying fruit and vegetables, coffee pulp, distillery grains, fish remains, and especially animal manure and human excrement (Huis et al., 2013).

Contrary to what was previously thought about the black soldier fly, in which adult insects sustained themselves exclusively from the fat reserves accumulated in the larval stage, recent studies investigating the midgut of adult BSF have reported that these flies can ingest and digest food. The quality and quantity of the ingested food affects the longevity of the flies. These findings suggest that adult BSF does not exclusively rely on nutrient and energy reserves accumulated during the larval stage (Bruno et al., 2019)

The nutritional composition of black soldier fly larvae meal varies depending on the chemical composition of the feeding substrate (Spranghers et al., 2017; Meneguz et al., 2018) and the weight and developmental stage of the larvae (Lalander et al., 2019). In general, they are rich in protein (350 to 610 g/kg crude protein) and lipids (70 to 420 g/kg ether extract) (Barragan-Fonseca et al., 2017). In addition, BSF contains 0.8–9 g/kg methionine, 3.4 to 33 g/kg lysine and 2.2 to 22.6 g/kg threonine (Elahi et al., 2022). Another important component of the composition of BSF larvae is chitin, present in the insect's exoskeleton (Xiong et al., 2023). This non-starch polysaccharide can be found in black soldier fly meals at levels of up to 87 g/kg and can reduce the digestibility of nutrients in the diet (Kroeckel et al., 2012). On the other hand, lower levels of chitin can increase the activity of the innate immune system and exert antibacterial effects (Xu et al., 2013).

According to Makkar et al. (2014), the larvae of the black soldier fly are a food source rich in fats, with a lipid content that varies from 7% to 39% in dry matter, depending on the substrates used to cultivate the larvae (Barragan-Fonseca et al., 2017). The lipids in BSF larvae can replace soybean oil in animal feed. Studies have shown that there were no adverse effects on the development and growth of chickens and Jian carp (Cyprinus carpio var. Jian) when 100% soybean oil was replaced with fat from *Hermetia illucens* larvae in the animals' diets (Schiavone et al., 2018).

Zotte et al. (2019) evaluated the black soldier fly (Hermetia illucens) as a food source for laying quails, analyzed live performance, the physicochemical quality of the eggs, the sensory profile and storage stability. They concluded that, based on the results of the experiment, black soldier fly larvae meal can be considered an alternative ingredient to soybean meal in diets for laying quails, up to an inclusion level of 15%. No negative effects were observed on the productive performance of the birds, and the eggs generally had satisfactory physicochemical characteristics and sensory profile in general.

Silva et al. (2024), when evaluating the effects of larvae meal from the black soldier fly (*Hermetia illucens*) on quail performance, concluded that the inclusion of 100 g/kg larvae meal improves the feed conversion ratio for growing quails, highlighting the potential of using insects in quail feed.

CONCLUSION

Incorporating insects and their co-products into quail feed is proving to be a solution that is not only viable, but also highly sustainable and innovative. The nutritional benefits associated with these ingredients, with their rich protein, amino acids and fatty acids, position them as a promising alternative for meeting the specific needs of quail. In addition, the sustainability inherent in insect production offers a responsible approach, which is in line with growing environmental concerns and the search for greener feeding practices in poultry farming.

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