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The Impact of Alternative Insect Protein Sources on Poultry: Performance and Sustainability (Article review)

Ahmed M.Th. Al-Niemy* and Sarmad H. Al-Maula

Animal Production Department, College of Agriculture and Forestry, University of Mosul, Iraq

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***Corresponding author:** ahmed.alniemy@uomosul.edu.iq

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Abstract: A promising agricultural revolution in the poultry feed sector is represented by the production of alternative insect proteins derived from sources, through transforming the production process towards sustainability systems. These insects cannot be limited to being rich in protein only. Rather, these proteins provide high nutritional value with an ideal composition of essential amino acids that meet poultry's basic needs for growth and production. Therefore, all forecasts for the near future indicate the possibility of rapid growth in the insect feed market. One of the things that will accelerate the realization of these forecasts is the increasing rise in the prices of traditional proteins, in addition to the increase in environmental awareness. Modern technological innovations have the ability and efficiency to develop breeding, production and processing processes for insect protein, which enhances cost competitiveness. This will lead to the introduction of other types of feed substitutes in poultry feed. Therefore, insect protein will become the cornerstone of the circular economy for animal production, in addition to reducing the carbon footprint of farms by using organic waste and converting it into valuable materials. What distinguishes it from other protein alternatives derives from its excellent nutritional quality, high digestibility coefficient, and consequent enhancement of growth, development, as well as increased meat palatability and higher carcass and egg coefficients. This alternative protein replaced traditional protein sources in poultry feed at a rate different ranging with insect protein powder, and no adverse effects were observed on the growth of these animals. In some recent studies, manufactured feeds whose main protein is an alternative insect protein have been superior to manufactured feeds from traditional protein sources. Insect powder added to feed is considered a direct and applicable protein substitute that increases the profitability of breeders economically because it enhances their growth rates and (FCR). In addition, the production of traditional plant proteins has an environmental impact that is considered harmful compared to insect protein because it comes from sources that are considered a burden on the environment and inexpensive, and for that reason it can be included as one of the long-term solutions to preserve the environment, enhance animal production, and increase the profitability of breeders.

Key words: Alternative, Insect, Performance, Sustainability, Poultry.

Introduction

There are over 2,000 insect species on Earth that can be used as insect protein, and many researchers have been studying them for many years **(Jongema, 2017)**. With global population expansion fuels animal protein continues to rise, making it increasingly difficult to provide sufficient quantities to ensure food security. Poultry production is considered a fundamental and crucial pillar in meeting this increasing demand, and providing poultry production of meat and eggs requires providing huge feed sources, as providing the protein needs of farm animals has become a key food security challenge at the global level **(FAO *et al.*, 2023)**. The problem begins here because providing feed ingredients like soybean meal in these quantities is economically costly. In addition to the difficulty of cultivating them, their consumption of large quantities of water, and the strain on agricultural soil, which negatively impacts the environment and sustainable development systems, researchers have been prompted to find alternative protein sources. **(Tacon and Metian, 2015)**, Reports indicate that the projected increase in the planet's population in the near future will put further pressure on resources, particularly freshwater, and will also increase harmful gas emissions. This is compounded by the increased difficulty in producing animal feed from grains following the spread of COVID-19 and the Russian-Ukrainian war. It has become necessary to find feed sources, especially protein sources other than traditional feed sources **(Laborde *et al.*, 2020)**. Insects in feed system of farm animals has been proposed as a prospective substitute in the future given their accessibility, and insects are grown on limited resources and do not compete with human consumption **(van Huis *et al.*, 2013)**. Because competition between animal feed and human food This exacerbates the anxiety about for the viability of producing and supplying protein sources for the animal sector, and given the increasing potential for food security deterioration and the urgent need to implement global sustainable development systems. Exploring alternative protein components in feed becomes crucial **(pexas *et al*., 2023)**, as developing alternative protein sources for poultry nutrition will positively contribute to reducing the pressure on traditional protein sources. This promotes the growth, sustainability, and stability of poultry production **(Iji *et al*., 2017)**, as protein is a cornerstone of nutrition and the most expensive component in poultry feed formulation **(Leinonen *et al*., 2012)**. insect protein (IP) sources may be considered as a suitable renewable choice for several reasons, including the low competition these proteins have with protein sources, the high biological protein, and the low impact on ecological of their production **(Oonincx and de Boer, 2012)**. Therefore, Multiple scientific studies show feasibility of introducing insects as a sustainable protein alternative in poultry nutrition and reducing reliance on other food sources **(Veldkamp and Bosch, 2015)**. Hence, scientific inquiry has prioritized on the (BSF), (HFL), (YMW), silkworm, earthworm, cricket, and grasshopper. The aforementioned insect protein sources, especially the (BSF), (YMW), and (HFL), are among the most well-known of these sources and are being applied in poultry feed as a suitable substitute to (SBM), given their identification as a sustainable and important source of proteins used in poultry feed **(van Huis *et al*., 2013)**. Insects are among the (PS) that can meet the nutritional needs of poultry due to their high biological value and content of all (EAA). Also these sources are easily digestible and highly palatable to poultry **(Makar *et al*., 2014)**. These are rich sources of peptides with antimicrobial effects and compounds that are biologically active and contribute primarily to improving the overall health of the animal **(Fieldkamp *et al*., 2022)**. One of the reasons that increases societal demand for the use of substitute (PS) is to achieve three main goals that can be summarized as the ecological balance of animal production and reducing the impact of this production on the environment **(Poore and Nemecek, 2018)**. Likewise, adopting systems for the production of healthy feeds in order to alleviate chronic diseases and facilitate the management and care of animals **(Willett *et al*., 2019)**. For this reason, alternative protein is closely linked to sustainability and reducing the impact of poultry production on the environment **(Smetana *et al*., 2016)**. One of the advantages of using insects (PS) is their ability to reduce the cost of manufactured feed, in addition to the low cost of producing this protein, and the absence of negative ecological impacts. Rather, they are considered beneficial projects for a sustainable ecological. In addition, using these sources as effective substitutes to (SBM) does not affect the production process **(Bovera *et al*., 2016)**. Accordingly, this review was prepared to determine the importance of insect protein sources and the possibility of replacing them in rations as a primary alternative to soybean meal in poultry rations, and the impact of this on animal productivity, reducing production costs, implementing sustainable development systems, and preserving environmental resources.

proteins

It is a fitting name for this complex compound, as proteins are among most available organic molecules in living cells, representing 50% or more of their dry weight. It also plays a prominent role in all the vital processes that take place within the body of a living organism. Proteins are among the most important pillars of the life of a living organism in terms of structure and function. In addition, the genetic code that is passed down from one generation to the next is stored by nucleic acids **(Alberts *et al*., 2022)**. Moreover, proteins are considered a cornerstone of specialized functions, including acting as cofactors such as enzymes involved in multiple metabolic processes, as well as having structural functions, as in proteins that are involved in the structure of muscles, connective tissues, skin, feathers, and beaks **(Lodish *et al*., 2021)**. Some specific proteins have essential roles in the structural integrity of tissues, while others perform transport functions, such as hemoglobin, which is the primary carrier of oxygen. Another group of proteins acts as hormones. Furthermore, there are proteins that have defensive functions in the body, such as antibodies, which are proteins that have a high degree of specialization in immune action to protect the body from bacterial and viral contagions **(Janeway *et al*., 2001)**. In addition to blood clotting processes, the transport of endogenous vitamins in the blood, the transport of oxygen in muscles, and other functions of great importance in the vital activities that take place within the living body, proteins contain 50-55% carbon, 6.5-7.5% hydrogen, 19-24% oxygen, and 15-19% nitrogen **(Whitford, 2013)**. Proteins in tissues and food are estimated based on their nitrogen content. Some proteins contain sulfur in a proportion ranging from 0.5-2.5%, and others contain phosphorus in a proportion that may reach 0.8% **(Moughan, 2003)**.

Biological value of protein

One of the characteristics of proteins is that each protein has a specific combination of amino acids that are genetically passed down from one generation to the next in living organisms in exact copies **(Alberts *et al*., 2022)**. From this perspective, some proteins contain all the essential amino acids (EAA), while other proteins are deficient in one or more of the (EAA) **(Wu, 2016)**. Value of a protein is high if its composition contains all the (EAA) in the proportions required by the organism to carry out the various vital processes **(WHO, 2007)**. However, if the protein is lacking in one of the (EAA), its biological value decreases significantly. The (AA) configuration relies on the relative composition of the monomeric proteins present in that substance **(Millward, 2012)**. Based on this, the protein quality index is expressed by the percentage of nitrogen that can be assorbed, that the body can use for growth or to replace damaged parts, and that can be stored in the body and not excreted in urine. For example, the biological value of the protein in an egg is 100%, meat protein 79-95%, grain protein 62-68%, and gelatin 0% respectively **(Hoffman *and* Falvo, 2004)**. The vital value depends largely on the protein level in feed. If the protein at the minimum level required by the bird, the vital value is at its highest level. However, when protein levels are higher than the growth level and above the limits required by the bird, the vital value begins to decrease **(Baker, 2009)**. In general, not all types of plant proteins used in poultry feed are beneficial to birds when used directly, as soybeans, commonly incorporated plant protein sources in poultry diets, suffer from a deficiency of methionine, which is one of critical (EAA) in poultry feed **(Friedman and Brandon, 2001)**. In addition to the above, untreated soybean seeds have negative effects on the bird, as they lead to negative effects by inhibiting digestive enzymes, especially those responsible for protein digestion, causing pancreatic enlargement, preventing the absorption of nutrients in young chicks, or those that limit chick growth **(Liener, 1994)**.

Alternative proteins

The competition that has been occurring for many years between animals feed components and humans food, in addition to the general trend towards implementing sustainable development systems and goals, are considered the initial spark in the process of creating and developing alternative proteins. Insects are considered one of the sources that are being scientifically and practically turned to for inclusion as an substitute (PS) in poultry ration in order to reduce this competition (van Huis, 2013). There are more than 13 types of insects that can be included in poultry feed, and some of them have been approved under European Union regulations **(Lähteenmäki-Uutela *et al*., 2021)**. Substitute (PS) may be categorized as five categories relative to their source, availability in large quantities in the markets, and, primarily, their prices. The first category, in terms of reliability in poultry feed, is primarily based on legume seeds as an alternative to soybean seeds, However, the drawback is that most of these alternative legumes contain some inhibitory and anti-nutritional compounds. These compounds are not considered to be essential barriers that prevent their use and can be overcome through systematic selection **(Samtiya *et al*., 2020)**. The most trusted feed by poultry farmers is oilseeds, but the determinants of the amount of protein in these seeds vary according to the amount of oil extracted from them **(Hincheon *et al*., 2017)**. Similarly, green fodder and leaf protein have been substituted as protein sources, but many limitations hinder their use **(Santos-Sanchez *et al*., 2019)**. There are other by-products from the production of ethanol and starch, and these products have recently begun to spread as they can be used as protein substitutes (SBM) **(Lyons *et al*., 2015)**. However, its drawback is that the amino acid composition in these byproducts is unbalanced, with a deficiency in essential amino acids. Therefore, when using them in poultry feed, supplementation of the missing amino acids must be considered **(Ravindran, 2013)**. The fifth category in terms of reliability in poultry feed consists of algae and insect proteins, which have been introduced as new alternative protein sources in the last decade, although their availability and use are still relatively limited. However, all current predictions and data indicate that it will soon become an alternative protein source in animal feed **(Rumpold and Schlüter, 2013)**. These (ps) have been tested and proven effective enhancing the growth performance of broiler chickens by more than 3% and improving egg production from laying hens by more than 5% **(Gasco et al., 2018)**. Insect-based feeds, which are a primary protein source, have been introduced to the market and have gained wide acceptance among breeders due to their ability to improve feed quality and nutrient utilization, in addition to enhancing performance, utilization nutrient utilization efficiency, and optimizing the health status of poultry **(Veldkamp *et al*., 2022)**. In addition, the cost of producing feed mixtures is a major financial obstacle, as feed production contributes about 60-80% of total costs, and about 70% of these costs come from the use of soybean meal as a (PS). Therefore, insect-based protein alternatives were sought to reduce feed costs **(FAO, 2022)**. For these reasons, the growing acceptance of substitute protein sources and the adoption of sustainable development projects by developed and developing countries accelerated the search for sustainable feed alternatives with minimal environmental impact and lower costs. Because traditional feed production projects have had negative impacts on the environment and climate, in addition to their production being relatively expensive, one of these projects is the feed protein production project based on methane gas. The idea of this project lies in producing single-cell protein from microorganisms that are fed on methane gas **(Lennen and Pfleger, 2013)**. Some types of bacteria are used in food fermentation or for wastewater treatment **(Wendisch *et al*., 2016)**. Additionally, there is a project to produce feed alternatives from algae and cyanobacteria, and for this purpose, a specialized center for applied algae research has been established **(Caporgno and Mathys, 2018)**. Algae are autotrophic organisms that perform photosynthesis **(Becker, 2007)**. Microalgae are characterized from stems from its rich nutritional profile, their ecological friendliness, and their ability to utilize waste products, which are a burden on the environment, as a food source , Seaweed, classified as brown, red, and green algae, is a promising source of alternative protein, especially red algae **(Bleakley and Hayes, 2017)**. Phicobellinates are the main proteins in microalgae, and they are categorized into several types based on light-absorbing attributes **(Pagels *et al*., 2019)**. Lectins are the main proteins in seaweed **(Holdt and Kraan, 2011)**. Previous research has been conducted in several countries worldwide to develop a project combining these two products This is achieved by producing feed protein consisting of a mixture of microalgae and beneficial microbes produced in wastewater treatment plants to utilize the large quantities of natural methane gas produced from them **(Arias *et al*., 2021)**. The bacteria are characterized by high biological value, also to their ability to use nutrients efficiently **(Ritala *et al*., 2017)**. Fungi are systematically categorized into two main types: filamentous and non-filamentous fungi. Fungi are considered a highly important (PS) in plant-based diets **(Feeney *et al*., 2014)**. Fungal proteins possess diverse biological and medicinal value **(Rahi and Malik, 2016)**. The preceding account of feed protein production techniques based on microorganisms and algae, which have been used in Europe for many years, reveals that these techniques have not received the same level of attention as insect-based protein production projects. The EU Parliament's ENVI Committee recently granted official approval to a proposal to use insect protein in poultry feed

(European Parliament, 2020), which was endorsed by (FAO) **(FAO, 2021)**. The trend towards insect protein production technologies, their development, and the ongoing research conducted on them, and considering them as the basis of alternative proteins, is due to the ease of their production compared to microbial protein, in addition to the fact that they are low-cost and do not require large capital, as well as because they have a very limited environmental impact and are compatible with sustainable development systems **(Oonincx and de Boer, 2012)**. In addition, industrial safety precautions in their breeding areas are almost negligible, and also because the basic building block of insects selected in animal protein projects was chosen by the FAO and the European Organisation for the Safety of Protein Produced from Toxins and Pathogens **(EFSA, 2021)**. Because diseases that are common between humans and arthropods are almost non-existent, and the ability to produce safe insect protein that is free from the problems associated with the accumulation of metals and pesticides during their feeding on human food waste **(van Huis, 2020)**. Most importantly, raw used in the manufacture of insect protein are classified as waste that constitutes an environmental and financial burden, and thanks to this industry, they have become a free raw material for a strategic product **(Čičková *et al.*, 2015)**. It is known that poultry can consume multiple varieties of insects such as (BSF), flour beetles and other insects in the natural environment, but their use as feed on a commercial scale has not yet been produced **(van Huis, 2013)**. Proteins in insects are primarily found in muscle tissue, skin, and blood **(Li *et al*., 2021)**. (BSF) and (HFL) and the (YMW) are currently being studied and regarded as promising for feed production These insects are characterized by high nutritional value at all stages of their life cycle, also to their ability to lower carbon footprint and decrease waste production. However, weaknesses are represented by the legislative ban and the scarcity of companies operating in this field, and the shelf life of alternative proteins is subject to hygrothermal influences **(Schmidt *et al*., 2019)**. Furthermore, insect proteins are more susceptible to spoilage and oxidation during storage, in addition to the significant lack of funding, modern technological methods in production, human resource development, and the unregulated supply chain and supplier structure. Therefore, for these reasons, regulatory bodies are making great efforts to regulate insect production and use in feed **(Gomes *et al*., 2024)**.

Black soldier fly

Its considered a promising project for producing alternative proteins due to its properties that combine the application of sustainable environmental goals with reducing the financial and economic costs of poultry production this ability of larvae to convert organic waste from animal droppings and food scraps into high-biological-value protein and produce high-nutritional-value oils that can be used in feeding domestic animals **(Diener *et al*., 2011)**. This reduces reliance on traditional feeds, as this insect is widespread throughout most of the world **(Čičková *et al*., 2015)**, making these insects an effective tool for waste treatment and protein feed output, as (BSF) powder can be added to broiler chicken feeds that sustain normal growth rates and environmental sustainability **(Schiavone *et al*., 2017)**. Because it has similar efficiency to regular (PS) such as (SBM) in feed production, growth rates, and production indicators **(Bovera *et al*., 2016)**. It was also found that adding (BSF) powder to broiler chicken diets can reduce the number of Salmonella bacteria and promote and increase types of Lactobacillus bacteria in the intestines **(Biasato *et al*., 2020)**. Adding protein from (BSF) to poultry feed contributes to maintaining blood, liver, and kidney function, and planetary stewardship **(Cullere *et al*., 2019)**. These larvae can be easily reared in a sealed enclosure with a starting area of 50 square meters, expandable in the future, Regarding the temperature required for raising these larvae, it should be between 25-27 degrees Celsius, and the humidity should be around 50% with a good ventilation system **(Tomberlin *et al*., 2009)**. As for the equipment needed for raising them, you only need plastic boxes for raising the larvae, in addition to an automatic temperature and humidity control system, as well as equipment for collecting and separating the larvae from the waste, in addition to equipment for treating organic waste **(Sheppard *et al*., 2002)**. As for the raw materials needed to feed them, organic waste such as food scraps, vegetable peels and fruit scraps are considered the best feeding medium to meet the needs of larvae growth and reproduction, in addition to drinking water and maintaining humidity by placing a sponge inside the water container. The larvae need about 14-18 days to grow and turn into a source of protein **(Diener *et al*., 2011)**. The larvae are then collected and purified from the remaining organic waste, then they are dried in thermal ovens, and then these larvae are ground to obtain insect protein powder **(Spranghers *et al*., 2017)**. What is distinctive about the (BSF) is the shortness of its life cycle, which begins with the mating of the male and female, after which lays between 320 and 1000 eggs hatch after only 3 to 4 days **(Tomberlin and Sheppard, 2002)**. The female then dies a few hours after the egg-laying process as a result of using all the fat stored in her body during the egg-laying process, as the black soldier fly larvae appear very small in size after hatching, to the point that they can be difficult to see with the human eye **(Sheppard *et al*., 2002)**. The larvae then gradually change color from beige to black as they prepare to enter the pupa. After that, the adult black soldier flies emerge from the pupa after a period of 4 to 5 days **(Tomberlin *et al*., 2009)**. The nutritional importance of insect powder lies in its high protein content, which can reach between 40% and 45% **(Rumpold and Schlüter, 2013; van Huis, 2013)**. It can even surpass soybean meal because insect protein contains higher concentrations of (EAA) **(Makkar *et al*., 2014)**. It also has a high digestibility coefficient that can reach 90% **(Bosch *et al*., 2020)**, Moreover, the elevated lipid composition with outstanding dietary value as it contains abundant unsaturated fatty acids **(Barroso *et al*., 2014)**. For this reason, insects possess a relatively high energy value, similar to that of legumes **(Nowak *et al*., 2016)**. Furthermore, they contribute significantly to reducing the costs of importing animal feed by producing high-quality, locally sourced feed at virtually no cost, this reduces reliance on imported traditional feed and lowers the costs of raising and producing poultry **(van Huis, 2013)**. In terms of sustainability, this project contributes significantly to the process of managing organic waste, As the larvae grow and develop, they decompose organic waste, reducing environmental pollution and ensuring the safe and beneficial disposal of this waste **(Lalander *et al*., 2019)**. Furthermore, this process generates relatively high economic returns. The production of protein from (BSF) insects constitutes a multi-source income through production at almost zero costs and through the sale of the produced larvae as ration, also the sale of the resulting organic fertilizer, making it a rewarding alternative to the use of soybean meal in several fields **(Salomone *et al*., 2017)**.

Yellow mealworm

(YMW) beetle passes through several life cycle, from egg to larva, then pupa, and finally adult (Ramos-Elorduy et al., 2002). Environmental conditions have effect on insect's life cycle and developmental stages, type of food the insect is reared on, as well as humidity, temperature, and the density of the breeding insects per unit area, are important. The insect needs about 60 days to complete its life cycle **(van Broekhoven *et al*., 2015)**. (YMW) are considered a modern and promising feed source for the future due to the possibility of producing them in large quantities on a commercial scale **(van Huis, 2013)**. What distinguishes these larvae is their impressive protein levels, with a composition that is similar to or sometimes even exceeds traditional protein sources of amino acids such as (SBM) **(Rumpold and Schlüter, 2013)**. In addition, yellow mealworm larvae are packed with energy and high in beneficial unsaturated fatty acids for poultry nutrition **(Barroso *et al*., 2014)**. There are biologically active peptides in the larvae that have an effective ability to promote general health **(Van Brockhoven *et al*., 2015)**. Also possibility of raising them on organic biological resources of low nutritional value or on byproducts from grain processing operations and using them as a highly efficient feeding medium **(Oonincx *et al*., 2015)**, their water requirements are almost non-existent when compared to traditional methods of plant protein production **(Miglietta *et al*., 2015)**. Temperature has a direct effect on the number of incubation days for eggs, which varies from 4 days if the ambient temperature is 26-30 degrees Celsius, but if the ambient temperature is 15 degrees Celsius, the number of incubation days for eggs increases to 34 days **(Rumbos *et al*., 2020)**. The eggs of the (YMW) beetle have a high hatching rate, which can reach 70% at an ambient temperature between 17.5 and 27.5 degrees Celsius. **(Morales-Ramos *et al*., 2013)**. Newly hatched larvae are predominantly pale white and are about 0.34 cm long, but when they reach sexual maturity they reach about 3.16 cm **(Ghali and Al-Kwik, 2009)**. The larvae are cylindrical in shape, and their final weight reaches about 0.2 grams. In order to reach this weight, they need (2-4) months, as the period decreases as the temperature is suitable for growth and the availability of the food necessary for their growth **(Van Brockhoven *et al*., 2015)**. After that, it turns into a pupa in about 5-9 days, and then into an adult beetle **(Morales-Ramos *et al*., 2013)**. The adult beetle is predominantly dark in color, and its lifespan ranges from (37-97) days **(Rombos *et al*., 2020)**. The usability of YMW in feed varies according to its age stage, as we find that the best nutritional value for feeding animals and the highest digestibility coefficient are found when it is in the larval stage compared to the pupa and adult insect stages **(Mendoza-Salazar *et al*., 2021; Oonincx and Dierenfeld, 2012)**. Wheat bran is considered the best food source for insect development and to ensure its reproduction **(Rumbos *et al*., 2020)**. This is because they contain a high percentage of protein, fiber, and soluble carbohydrates that meet their needs **(Oninex *et al*., 2015)**. In addition, organic waste, such as vegetable and fruit scraps, can be used **(Lalander *et al*., 2019)**. However, it is important to maintain appropriate moisture levels for these wastes before introducing them to insects **(Čičková *et al*., 2015)**. Relying on organic bio-waste helps reduce the amount of wasted organic matter that burdens the environment and also provides a sustainable source of mealworms **(Salomone *et al*., 2017)**. Although organic waste shows limited availability of nutrients compared to wheat bran, these insects can transform it upon maturity into a natural protein content of high nutritional value, and sometimes the protein content surpasses that of the nutrient medium **(van Huis, 2013)**. One of the most important nutritional components of this insect is its integrated composition, as crude proteins constitute about 50% of its dry weight, while fats constitute about 30%. It is worth noting that these percentages may vary according to the nutritional medium on which this insect is grown **(Van broekhoven *et al*., 2015)**. Also the larvae have in terms of containing appropriate proportions of (EAA) and (non-EAA), as well as being rich sources of saturated (FA) and unsaturated (FA) **(Rumpold and Schlüter, 2013)**. It also contains high levels of minerals and vitamins, including phosphorus, potassium, magnesium, zinc, iron and copper, in addition to a group of B vitamins (B2, B3, B5, B12) and vitamin (E) **(Finke, 2002)**. The oil found in mealworms is characterized by its high content of tocopherols and polyphenols, which possess potent antioxidant properties **(Zielińska *et al*., 2015)**. However, a drawback of this insect, limiting its use, is its calcium deficiency **(Finke, 2002)**. Therefore, using this insect as an animal protein may require supplementing feed with additional calcium supplements, in addition to the fact that chitin affects the protein digestion process and health of poultry **(Kierończyk *et al*., 2018)**.

Housefly

It's a promising substitute (PS) in poultry diets, owing to its superior nutritional quality, particularly protein. These insects are considered an integral constituent of the diet of birds in their wild habitats, It is considered one of the most widespread types of insects (under the order Flies), as it is a global pest and one of the main vectors of diseases **(Hwangbo *et al*., 2009)**, as its larvae and adult insects feed on organic animal waste and decaying refuse, one of the merits of (HFL) is ability to reproduce by converting organic waste into biomass with a protein-packed and fat **(Čičková *et al*., 2015)**. Since the late 1960s, the possibility of producing an alternative insect protein from housefly larvae using various production methods and incorporating it into farm animal feed has been studied. Studies have shown that (HFL) reared on poultry litter can be used as a high-biological-value (PS) in poultry diets **(Calvert *et al*., 1970)**. In the 21st century, research has emerged on the use of (HFL) in fish farming in aquariums **(Wang and Shelomi, 2017)**. The life cycle of the housefly is defined by its shortness and rapid completion in the natural environment, where fly eggs hatch in only 8-12 hours. After that, it takes about 5 days for the growth stage, followed by the pupal stage (4-5 days), especially when ideal conditions are available. As a result of the above, the life cycle of the housefly usually takes only 6 to 10 days **(Lysyk, 2022)**. As for the ability of females to lay the quantity of eggs, it varies according to the conditions, as the number of eggs laid is about 500-600 eggs in uncontrolled environmental conditions, while when flies are reared in controlled conditions, they can lay more than 2000 eggs **(Morales *et al*., 2022)**. Female flies prefer moist places to lay eggs, especially in dung and decaying organic waste **(Čičková *et al*., 2015)**. Because the larvae need nutrients intensively for 4-5 days, after which they need dry locations to enter the pupation process **(Kumar *et al*., 2022)**. Adult flies rely on decaying organic matter for their diet, which they can utilize through a special mechanism that liquefies the food by secreting saliva **(Stoffolano *et al*., 2023)**. A valuable feature of the housefly is its high ability to convert food, and for this reason it can be produced commercially using limited quantities of food media. Studies indicate that 450 grams of fresh animal waste can grow about 1500 larvae **(Calvert *et al*., 1970)**. This makes it a promising economic option in alternative protein production systems and sustainable animal feed production. Despite the anticipated benefits mentioned above, the use of houseflies in poultry feed raises many questions regarding poultry safety and biosecurity due to their primary role in disease transmission, Studies have shown that this fly has major health problems related to its mechanical transmission of more than 100 infectious diseases.

Escherichia coli, enterobacteria, sinensis virus A, cholera, salmonella, and skin infections are among the diseases that can be transmitted by the housefly **(Sze *et al*., 2023)**. Therefore, to ensure the complete eradication of these diseases, they must be biologically treated in a concentrated manner before being introduced into poultry feed **(Charlton *et al*., 2015)**. These larvae contain a high protein content exceeding 45% and are characterized by a complete amino acid profile, being rich in (EAA). The larvae were found to contain up to 20% fat, while protein was found to be around 51.7%, fats around 11.3%, ash 28.9%, and nitrogen-free extract 8.1% **(van Huis *et al*., 2013)**.

Table (1). Shows the comparison between the ingredient profile of (BSF), (YMW), (HFL) and (SBM)

Nutritional component	(BSF)	(YMW)	(HFL)	(SBM)
Crude Protein%	40.1 – 45.8 **(Barragan-Fonseca *et al*., 2017)**	45 – 55 **(Janssen *et al*., 2017)**	45 – 65 **(Makkar *et al*., 2014)**	43.0 – 48.5 **(NRC, 1994)**
Crude Fat%	25.6 – 34.8 **(Barragan-Fonseca *et al*., 2017)**	25 – 35 **(Janssen *et al*., 2017)**	15 – 35 **(Makkar *et al*., 2014)**	1.0 – 2.0 **(NRC, 1994)**
Crude Fiber%	6.5 – 12.0 **(Schiavone *et al*., 2017)**	5 – 10 **(Rumpold *and* Schlüter, 2013)**	6 – 12 **(Henry *et al*., 2015)**	5.0 – 7.0 **(NRC, 1994)**
Ash%	10.5 – 15.0 **(Schiavone *et al*., 2017)**	3 – 5 **(Rumpold *and* Schlüter, 2013)**	5 – 10 **(Henry *et al*., 2015)**	5.0 – 6.5 **(NRC, 1994)**
Calcium (Ca)%	5.0 – 8.0 **(Schiavone *et al*., 2017)**	0.1 – 0.3 **(Finke, 2013)**	0.5 – 1.5 **(Sánchez-Muros *et al*., 2014)**	0.2 – 0.4 **(NRC, 1994)**
Phosphorus (P)%	0.8 – 1.5 **(Schiavone *et al*., 2017)**	0.7 – 1.2 **(Finke, 2013)**	0.8 – 1.5 **(Sánchez-Muros *et al*., 2014)**	0.6 – 0.8 **(NRC, 1994)**
Methionine%	0.6 – 0.9 **(Marien *et al*., 2022)**	0.8 – 1.2 **(De Castro *et al*., 2021)**	1.0 – 1.8 **(Veldkamp *and* Bosch, 2015)**	0.6 – 0.7 **(NRC, 1994)**
Lysine%	2.4 – 3.2 **(Marien *et al*., 2022)**	2.5 – 3.5 **(De Castro *et al*., 2021)**	3.0 – 4.5 **(Veldkamp *and* Bosch, 2015)**	2.8 – 3.1 **(NRC, 1994)**
Metabolizable Energy (MEn) kcal/kg	3500 – 4000 **(Marien *et al*., 2022)**	3800 – 4500 **(Bovera *et al*., 2018)**	3500 – 4200 **(Tran *et al*., 2015)**	2200 – 2450 **(Ravindran, 2013)**

Nutritional value of insect protein

Recently, the demand for alternative proteins has increased due to many factors, including the scarcity of fertile land and fluctuations in climatic conditions **(Foley *et al*., 2011)**. Insects dedicated to producing alternative proteins need small surface areas in addition to reducing harmful gas emissions **(Oonincx and de Boer, 2012)**. Species such as (BSF), (HFL), and the (YMW) are considered novel and energy-rich protein sources, in addition to their outstanding substance of (AA) and (FA) **(Rumpold and Schlüter, 2013)**. Their nutritional value is determined according to their breeding conditions, the age at which they are used in poultry feed, and the methods of processing insect protein **(Barragan-Fonseca *et al*., 2017)**. Insects vary from species to species in their concentration **(Nowak *et al*., 2016)**. Their energy content in adult insects is often lower than in the larval and pupal stages **(Oonincx *et al*., 2015).** Evidence has corroborated the digestibility levels of insect powder species in poultry vary **(De Marco *et al*., 2015)**. Insect meal bioavailability is contingent upon a range of aspects, for instance the insect variety, the percentage added, and the processing techniques **(Kierończyk *et al*., 2018)**. Furthermore, Chitin in insect exoskeletons impairs nutrient digestibility. However, in general, insect protein alternatives are considered among the most important new formulations that can be introduced into animal feed **(Gasco *et al*., 2018)**. (BSF) are considered an appropriate protein substitute in ration, but their fat content can reduce their palatability and digestibility **(Spranghers *et al*., 2017)**. In broiler chickens, insect powder can improve feed conversion ratio and meat quality, this improvement is believed to be a result of increased digestibility of the various feed components, and the digestibility and absorption of amino acids in insects are high **(Bovera *et al*., 2016)**. The total digestibility of different types of insect powder varies depending on the dry matter **(Mohan *et al*., 2022)**. Evidence has corroborated the importance of insect powder through its biologically active effects of insect peptides **(Vercruysse *et al*., 2005)**. Insect-derived biologically active substances can be classified into antimicrobial peptides and fatty acids **(Veldkamp *et al*., 2022)**. Peptides act as antimicrobials, such as nisin, as natural antibiotics **(Cotter *et al*., 2005)**. Different types of these peptides, such as alpha-helix peptides and cysteine-rich peptides, target different types of bacteria through various mechanisms and modes of action **(Brogden, 2005)**. In addition, lauric acid, a medium-chain saturated (FA) found in the larvae of the (BSF) before pupation, has antimicrobial and antiviral properties **(Spranghers *et al*., 2017)**. Chitin are polysaccharides found in insects, also have antimicrobial and antiparasitic properties, as well as immunomodulatory effects, which contribute to enhancing poultry health when added to their diets **(Mohan *et al*., 2022)**. The use of insect powder in poultry feed faces many challenges and limitations, entailing expensive processing costs, governmental regulations, the limited taxonomic range of insects that can be raised **(Lähteenmäki-Uutela *et al*., 2021)**. This necessitates further economic studies to mitigate these obstacles and maximize insect production by companies **(Smetana *et al*., 2016)**. It also requires selecting appropriate insect species and neutralizing anti-feeding substances through the application of modern processing techniques **(Kironcik *et al*., 2018)**.

Use of insect protein substitutes and their effect on poultry performance

Different effects on growth rate were observed when different proportions of houseflies were substituted into broiler chicken diets **(Wang *et al*., 2022)**. The same result was observed when mealworm powder was added **(Bessa *et al*., 2020)**. BSF is considered one of the best currently available alternatives to SBM **(Schiavone *et al*., 2017)**. Other insect protein sources used in poultry feed include locusts and worms **(Khusro *et al*., 2022)**. It has been documented that the harmful environmental impact of using insect powder in poultry feed can be reduced compared to using traditional plant proteins **(Owenkes and de Boer, 2012)**. This also reduces costs and the environmental footprint of animal production **(Owenkes *and* de Boer, 2012)**. In addition to improving growth and increasing the quality of poultry meat **(Bofira *et al*., 2016)**, insect proteins have been observed to increase production rates **(Mustafa *et al*., 2025)**, leading to the attainment of the highest key production characteristics **(Al-Niemy *et al*., 2025).**

Restrictions on the substitution of insect powder in ration

Public safety is a crucial factor to consider when using insects as animal feed, given the potential consequences for both animal and human health **(European Food Safety Authority, 2015)**. Among the most significant challenges are the microbiological risks that insects may carry, such as bacteria, viruses, and parasites **(Charlton *et al*., 2015)**. In addition to the potential presence of mycotoxins in insects **(Gasco *et al*., 2020)**, there are also chemicals, such as heavy metals and pesticides, that are harmful to animals and potentially transmissible to humans **(Van der Wels-Clerks *et al*., 2018)**. Similarly, allergic reactions can occur as a result of consuming insect powder, with chitin playing a key role in these health problems **(De Geer and Verhoex, 2018)**. Furthermore, some insects can have an anti-nutritional effect, thus affecting digestion and absorption **(Kironczek *et al*., 2018)**. Each country has its own regulations and laws governing the use of insects as animal feed **(Lähteenmäki-Uutela *et al*., 2021)**. In the European Union, bovine spongiform encephalopathy (BSE) and bovine spongiform encephalopathy (BSE) are major obstacles to using insects as feed **(EFSA, 2021)**. Therefore, the types of insects and the conditions necessary for their use in poultry diets have been specified by regulatory bodies **(IPIFF, 2021)**.

Table (2). A realistic comparison between insect larvae (BSFL, YMW, HFL) as (PS) in feed and their effect on poultry

Characteristics	(BSF)	Reference (BSF)	(YMW)	Reference (YMW)	(HFL)	Reference (HFL)
Protein digestibility index	75-85%	**(Maurer *et al*., 2016)**	80-90%	**(Bovera *et al*., 2016)**	85-92%	**(Hwangbo *et al*., 2009)**
Fat digestibility index	85-92%	**(Maurer *et al*., 2016)**	90-95%	**(Bovera *et al*., 2016)**	88-94%	**(Hwangbo *et al*., 2009)**
Chitin on digestion	Reduces protein and fat digestion at high levels	**(Spranghers *et al*., 2017)**	Moderate impact	**(Bovera *et al*., 2018)**	Relatively low	**(Veldkamp *and* Bosch, 2015)**
Amino acid availability	(Acceptable) (methionine is good, lysine is lower	**(Schiavone *et al*., 2017)**	(Very good) balanced amino acids	**(De Castro *et al*., 2021)**	(Excellent high) methionine and lysine	**(Veldkamp *and* Bosch, 2015)**
Bioactive peptides	Moderate content (antioxidant properties)	**(Bruni *et al*., 2020)**	High content (more studied)	**(Zhao *et al*., 2016)**	Very high content (more diverse)	**(Xia *et al*., 2021)**
Lauric acid	Very high (25-50% fat) - strong antimicrobial	**(Józefiak *et al*., 2016)**	Low	**(Oonincx *et al*., 2015)**	High (antimicrobial)	**(Makkar *et al*., 2014)**
Available minerals	Very high calcium	**(Józefiak *et al*., 2016)**)	Balanced	**(Finke, 2013)**	Balanced and highly bioavailable	**(Sánchez-Muros *et al*., 2014)**
Cost and feasibility of production	(Excellent) Can be widely cultivated on various residues	**(Van huis, 2020)**	Good: Longer life cycle (4-6 months)mod erate cost	**(Oonincx *et al*., 2015)**	Excellent: Fast life cycle (10-14 days), high conversion efficiency, but requires a precise culture medium	**(Van huis, 2020)**
Biosafety	High quality: Feeds on fresh waste, relatively low risk of microbial contamination.	**(van der Fels-Klerx *et al*., 2018)**	Moderate: May contain pathogens if fed on contaminate d waste	**(van der Fels-Klerx *et al*., 2018)**	High risk: Attracted to waste and manure, requires intensive sterilization before use	**(Charlton *et al*., 2015)**
Regulations	Globally approved (EFSA, FDA) for use in poultry and fish feed.	**(IPIFF, 2021)**	Globally acceptable	**(IPIFF, 2021)**	Acceptable but under strict conditions specific to the culture medium	**(IPIFF, 2021)**

Table (3). Shows poultry performance when insect protein is substituted in the diet

Characteristics	Chicken Breed	Insect Species and Replacement Rate	Observed Effect	Reference Sources
Daily Growth Rate	Broiler Chicken (Ross 308)	Housefly Larvae (10-15%)	Improves or equals control	**(Hwangbo *et al*., 2009)**
Daily Growth Rate	Broiler Chicken (Cobb 500)	Yellow mealworm (5-10%)	Significant improvement in growth	**(Bovera *et al*., 2018)**
Daily Growth Rate	Broiler Chicken (Arbor Acres)	Black soldier fly (10-15%)	Equals control or slightly less due to chitin	**(Schiavone *et al*., 2017)**
(FCR)	Broiler Chicken (Ross 308)	Housefly larvae (15%)	Improved conversion efficiency	**(Hwangbo *et al*., 2009)**
(FCR)	Broiler Chicken (Cobb 500)	Yellow mealworm (10%)	Slight improvement (1.49 in favor of soybean meal versus 1.52 in favor of yellow mealworm)	**(Bovera *et al*., 2018)**
(FCR)	Broiler Chicken (Ross 308)	Black soldier fly (15%)	Significant improvement (1.68 in favor of soybean meal versus 1.78 in favor of BSF)	**(Mwaniki *et al*., 2020)**
Egg production (%)	Laying hens (Lohmann Brown)	Black soldier fly (17%)	No statistically significant difference (92.1% for the control versus 92.8% in favor of the BSF)	**(Maurer *et al*., 2016)**
Egg production (%)	Laying hens (Bovans Brown)	Housefly larvae (10%)	Slight increase in production	**(Khusro *et al*., 2012)**
Egg production (%)	Laying hens (Hy-Line W-36)	Yellow mealworm (5%)	Production stability	**(Ravindran *et al*., 2020)**
Egg weight (g)	Laying hens (Lohmann Brown)	Black soldier fly (17%)	A slight decrease (61.2 in favor of soybean meal versus 62.1 in favor of BSF)	**(Maurer *et al*., 2016)**
Egg weight (g)	Laying hens (Bovans Brown)	Housefly larvae (10%)	Slight increase (62.3 in favor of the control versus 61.8 in favor of housefly larvae)	**(Khusro *et al*., 2012)**
Eggshell quality	Laying hens (Hy-Line)	Housefly larvae (8%)	Improvement in shell thickness and strength	**(Marono *et al*., 2017)**
Eggshell quality	Laying hens (Lohmann)	BSF (15%)	Improved due to calcium content	**(Star *et al*., 2020)**
Intestinal health	Broiler Chicken (Cobb 500)	Black soldier fly (10%)	Increased villus length and improved membrane integrity	**(Mwaniki *et al*., 2020)**
General immunity	Broiler Chicken (Ross 308)	Housefly larvae (5%)	Increased antibodies and improved immune response	**(Lee *et al*., 2018)**
General immunity	Broiler Chicken (Arbor Acres)	Black soldier fly (10%)	Stimulation of humoral immune response	**(Huang *et al*., 2021)**
Dressing percentage(%)	Broiler Chicken (Cobb 500)	Yellow mealworm (10%)	Slight increase (73.2% in favor of the control versus 72.5% in favor of the yellow mealworm)	**(Bovera *et al*., 2018)**
Dressing percentage(%)	Broiler Chicken (Ross 308)	(BSF) (15%)	No significant difference	**(Schiavone *et al*., 2017)**
Meat quality	Broiler Chicken (Ross 308)	(BSF) (10%)	Improvement in breast color (increased redness)	**(Schiavone *et al*., 2017)**
Meat quality	Broiler Chicken (Cobb 500)	Yellow mealworm (10%)	Increased unsaturated fatty acid content	**(Bovera *et al*., 2018)**

Conclusion

The trend towards adopting Substitute proteins, especially insect proteins, reduces the use of traditional plant protein and promotes self-sufficiency in animal feed. This transformation will establish new standards for sustainability in the sector, striking a balance between economic profitability, animal health and environmental responsibility, thus facilitating the provision of more diverse and sustainable feed for future generations.

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أثر مصادر البروتين الحشري البديلة على اداء الدواجن والاستدامة: مراجعة المقال

احمد محمد ثابت قاسم النعيمي و سرمد هاشم طه المولى

قسم الانتاج الحيواني ، كلية الزراعة والغابات ، جامعة الموصل ، العراق

الخلاصة

تُعد البروتينات الحشرية البديلة والمستخلصة من مصادر مثل يرقات الذبابة المنزلية وذبابة الجندي الأسود ودودة الوجبة الصفراء، ثورة زراعية واعدة في قطاع تغذية الدواجن، تهدف إلى تحويل سلسلة الإنتاج نحو أنظمة أكثر استدامة وكفاءة. توفر هذه البروتينات قيمة غذائية عالية الجودة، لا تقتصر فقط على محتواها البروتيني المرتفع، بل تشمل أيضاً تركيبة مثالية من الأحماض الأمينية الأساسية التي تلبي الاحتياجات الغذائية للدواجن. يتميز البروتين الحشري بمحتوى غني من الميثيونين واللايسين، مما يقلل الحاجة إلى الإضافات الصناعية لهذه الأحماض ويخفض تكاليف التصنيع. وتتجه التوقعات المستقبلية نحو نمو متسارع لسوق الأعلاف الحشرية، مدفوعاً بارتفاع أسعار البروتينات التقليدية وزيادة الوعي البيئي. من المتوقع أن تؤدي الابتكارات التكنولوجية إلى تحسين كفاءة عمليات التربية والإنتاج والتجهيز، مما يجعل البروتين الحشري أكثر قدرة على المنافسة من حيث التكلفة. ويتميز البروتين الحيواني بمعامل الهضم العالي والاستفادة الهضمية الكاملة مما النمو والتطور، بالإضافة الى ارتفاع قابلية الاستساغة والطراوة في اللحوم وارتفاع نسبة تصافي الذبيحة وكذلك استساغة البيض المنتج من الحيوانات التي تغذت على البروتين الحشري . لذلك فأن احلال هذا البروتين البديل محل مصادر البروتين التقليدية في علف الدواجن بمعدلات متفاوتة لم تُلاحظ أي تأثيرات مثبطة على نمو هذه الحيوانات. واحيانا تفوقت الأعلاف المصنعة التي يدخل البروتين الحشري البديل في تركيبها على الأعلاف المصنعة من مصادر البروتين التقليدية. يُعتبر مسحوق الحشرات المضاف إلى العلف بديلاً بروتينياً مباشراً وقابلاً للتطبيق يزيد من ربحية المربين اقتصادياً لأنه يعزز معدلات نموهم وكفاءة التحويل الغذائي. بالإضافة إلى ذلك، فإن إنتاج البروتينات النباتية التقليدية مثل (بروتين الصويا) له تأثير بيئي يعتبر ضاراً مقارنة ببروتين الحشرات، لأنه يأتي من مصادر تُعد عبئاً على البيئة ورخيصة الثمن، ولهذا السبب يمكن إدراج بروتين الحشرات كأحد الحلول طويلة المدى للمحافظة على البيئة وتعزيز الانتاج الحيواني وزيادة الربحية المربين.

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