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INSECTS AS AN ALTERNATIVE PROTEIN SOURCE IN POULTRY NUTRITION: REVIEW

Abstract. In today's world, poultry farming is the most dynamically developing branch of agro-industrial complex, providing the population of the planet with products of animal origin. However, poultry meat producers in developing countries face the challenges of high cost and low-quality poultry feed. Limited use of available protein sources forces professionals to consider using alternative protein sources such as forage insects. Due to high content of fat (30–40 %) and protein components (40–60 %) and wide distribution, insects are a cost-effective and potentially sustainable feed resource for poultry feeding. The conducted studies confirm that insect meal (larvae of black soldier fly, housefly, large mealworm, silkworm, grasshopper and locust) can be considered as a potential replacement for fishmeal and soybean meal in poultry feed mixtures. A review of scientific literature is presented, which highlights the use of insects as a source of protein and biologically active substances (polyunsaturated fatty acids and antimicrobial peptides) for poultry feeding and possibility of large-scale insect cliching for feed production. Information is provided on the chemical composition, nutritional and biological value of insect-based feed meal in comparison with soybean and fishmeal. There is practically no information in the literature about the negative consequences for chicken growth when using insect meal in feeding. Most scientific publications indicate that physiological indicators and productivity, when insect meal was used in poultry feeding, were practically not inferior to those in birds fed with soy or fishmeal. Thus, the use of insects as a feed component in poultry farming is a promising aspect for sustainable development of animal husbandry, which allows solving the problems of waste processing and rational use of feed resources.

Keywords: poultry farming, chicken feed, protein, insect meal

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ИСПОЛЬЗОВАНИЕ НАСЕКОМЫХ В КАЧЕСТВЕ АЛЬТЕРНАТИВНОГО ИСТОЧНИКА БЕЛКА В ПИТАНИИ СЕЛЬСКОХОЗЯЙСТВЕННОЙ ПТИЦЫ: ОБЗОР

Аннотация. В современном мире птицеводство является наиболее динамично развивающейся отраслью АПК, обеспечивающей население планеты продуктами животного происхождения. Вместе с тем производители мяса птицы в развивающихся странах сталкиваются с проблемами высокой стоимости и низкого качества кормов для сельскохозяйственной птицы. Ограничение использования доступных источников протеина вынуждает специалистов рассматривать возможность применения альтернативных источников белка, таких как кормовые насекомые. Благодаря высокому содержанию жировых (30–40 %) и белковых (40–60 %) компонентов и широкому распространению насекомые являются экономически эффективным и потенциально устойчивым кормовым ресурсом для кормления сельскохозяйственной птицы. Проведенные исследования подтверждают, что мука из насекомых (личинки черной львинки, комнатной мухи, большой мучной хрущак, шелкопряд, кузнечик, саранча) может рассматриваться в качестве потенциальной замены рыбной муки и соевого шрота в кормовых смесях для птицеводства. Представлен обзор научных литературных источников, в которых освещены вопросы использования насекомых в качестве источника белка и биологически активных веществ (полиненасыщенные жирные кислоты и антимикробные пептиды) при кормлении сельскохозяйственной птицы и возможность крупномасштабного клиширования насекомых для производства кормов. Приводятся сведения о химическом составе, пищевой и биологической ценности кормовой муки из насекомых в сравнении с соевой и рыбной мукой. В литературных источниках практически отсутствует информация о негативных последствиях для роста цыплят при использовании в кормлении муки из насекомых. В большинстве научных публикаций указывается на то, что физиологические показатели и продуктивность при использовании в кормлении птицы муки из насекомых практически не уступали аналогичным показателям у птиц, в рацион которых вводили соевую или рыбную муку. Таким образом, использование насекомых в качестве кормового компонента при выращивании сельскохозяйственной птицы является перспективным направлением устойчивого развития животноводства, позволяющим решить проблемы переработки отходов и рационально использовать кормовые ресурсы.

Ключевые слова: птицеводство, корм для кур, белок, мука из насекомых

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Abstract. Ensuring food security is an important area for the sustainable development of all countries on Earth [1]. Human population is expected to rise to about 9 billion by the year 2050 and possibly accompanied by 70 % increase in demand for animal proteins [2, 3]. This growth in population at a global scale has led to a global increase in food consumption patterns as well as changes in life styles and food preferences, which have increased the demand for animal protein [4–6]. This will affect the demand for livestock feeds, and inevitably place heavy pressure on already limited resources [7]. The increasing intensity of poultry production requires higher amounts of protein to cover the amino acid requirements for plumage development, growth and egg production [8]. Chicken producers are facing a lot of difficulties with availability and higher prices of feed ingredients [9].

The high prices of soybean meal and yellow corn mainly used for poultry diets formulation, are among the challenges to the poultry industry in developing countries. The cost of feed is between 65 and 70 % [10] and 70 and 75 % [11] of the total cost of production, as opposed to about 50 to 60 % in developed countries [12]. Reducing the cost of feed is therefore an important target in the poultry industry. Increased feed costs and limited amounts of animal protein sources in poultry feed have led to the use of alternative plant proteins that make up some or all animal protein in feed [13, 14].

Therefore, finding alternative sources of poultry feedstuffs is a recent research topic that is still under analysis by nutrition researchers in an attempt to find a balance between high performance and low cost. Due to high nutrient content and minimal environmental impact, insects have been considered as a potential dietary substitute for animals and humans [15–20]. Indeed, they generate low greenhouse gas and ammonia emissions, have a favourable feed conversion ratio and require small amount of water to grow [21]. Consumers seem to be willing to accept products obtained using these unconventional raw materials [22]. Moreover, they can provide animal feed bio-converting food wastes thus ultimately not competing with humans for natural resources [23–26]. Therefore, the objective of this paper is to review the current situation relating to the use of insects as a potential alternative protein source of feed for poultry.

Alternative Protein Feed Sources for Chicken. Plant and animal-based protein make up a large and important segment of an animal's diet. The usefulness of a protein depends on its ability to supply a sufficient amount of essential amino acids to the animal, particularly monogastric animals such as chickens, for production as well as the digestibility and toxicity of the protein. Proteins are made up of amino acids which are needed for the maintenance, reproduction and growth of animal. The main protein ingredients used in poultry diets are fishmeal and soya [27].

Currently available vegetable protein sources for poultry include soybean meal, rapeseed meal, legumes, and different cereal by-products [28, 29]. However, the demand for poultry feed will double, further increasing the demand for protein ingredients such as soybeans and cotton seed cake [30]. In addition to this, the amino acids composition of plant proteins for poultry is inferior to that of animal-based proteins, specifically with respect to their content of essential sulphur containing amino acids, in particular methionine. Soya beans are rich in oils (160–210 g/kg) and contain all the essential amino acids required for the animal for optimal performance; however, cysteine and methionine are below the required concentrations. This is a potential problem as methionine is the first limiting amino acid, especially in diets rich in energy [31]. On the other hand, the amount of land that can be used to grow soybeans and other plant sources of protein is decreasing globally, and overfishing in the seas has continued to limit the number of small pelagic forage fish, which are the primary source of fishmeal [32].

The decreased availability of essential amino acids for animals fed with plant protein sources will have a detrimental effect on growth and production. This problem can however be alleviated by the addition of animal sourced proteins in small quantities to strengthen the amino acid concentration in animal obtained from such feed [33] as blood meal and fish meal; or with the help of synthetic amino acids, although these are expensive. These animal-based protein sources are high in methionine, lysine, cysteine and tryptophan. Fishmeal however has been included into diets in limited amounts due to reduced availability. Fishmeal prices vary due to availability, and due to the ongoing reduction in fish stocks, fishmeal prices are also on the rise. It is believed that the price of fishmeal has already doubled in the last five years due to the increased scarcity of the resource [34]. This unfortunately affects the smaller scale farmers considerably as income does not always allow for expensive feed ingredients such as fishmeal.

As the ratio between the individual amino acids in protein concentrates varies significantly, supplementation with free synthetic amino acids would be successful. Especially when the variety of available raw materials makes it impossible to meet the requirements of the animal for all amino acids [33]. A viable alternative to the above mentioned may be in the form of insects as a source of protein in animal feeds. This will contribute to the recycling of food waste but at the same time produce a feed ingredient which is high in protein and fat for livestock [34–37].

Insect as Alternative Protein Source of Chicken Feed. The availability of essential amino acids (EAAs) to allow poultry to grow quickly in a short period of time is a crucial aspect of poultry nutrition. Due to this, soya bean meal (SBM) – based diets (which serve as the main source of protein in the diet) are combined with fish meal (FM) to make up for any amino acid (AA) shortfall in plant-based proteins [38]. The production of soybean involves deforestation, soil erosion, eutrophication, extensive use of pesticides, loss of biodiversity and a huge CO_2 footprint [39]. The rising price of soybeans has also recently become a crucial factor for the economic viability of the chicken meat sector, particularly in some emerging nations [40]. The FM is based on fish cultivated in aquaculture or marine fish species. Due to problems with over-fishing and environmental pollution, marine fish can be regarded as a limited resource. The rising price of soybeans has also recently become a crucial factor for the economic viability of the chicken meat sector, particularly in some emerging nations.

Insects are the most popular species comprising 70 % of animal species, and their biomass can be very high in some ecosystems. Most insects are native from the tropical and subtropical of the world. However, tropical and milder temperate zones between roughly 45°N and 40°S are now heavily infested by insects. There are extremely resistant insect species capable of dealing with demanding environmental conditions such as drought, food shortage or oxygen deficiency, like black solder flies larvae [41]. Entomophagy, the consumption of insects, is rooted in human evolutionary history. Insects have played an important part in the history of human nutrition in Africa, Europe, Asia, and Latin America. Over 1900 species of insects are known worldwide to be part of human diets. Over 1900 species of edible insects in 300 ethnic groups in 113 countries worldwide have been recorded by various authors to be part of human diet. According to Van Huis et al. [7], 246 species of edible insects have been reported in 27 countries in Africa. S. Kelemu stated that with 524 species identified from 34 African countries, Africa is one of the most significant hotspots of edible insect biodiversity in the world [42].

When compared to traditional fish and soybean meals, a variety of bug species have a higher protein content and an effective food conversion factor [43, 44]. In trials on animal feeding across bug species and animal production, insects can replace 25–100 % of soy meal or fishmeal, depending on the animal and insect type [21, 45–47]. Insects contain between 30 and 70 % of protein on dry matter (DM) basis and rich in fats, minerals and vitamins [48]. Some insects can store large amounts of lipids, and the extracted oil can be utilized for a variety of purposes, including generation of biodiesel [21]. Over 2000 species of edible insects have been identified, as well as their nutritional value as food and feed [6, 7]. Insect meal can replace soy-based protein feeds and is recommended for poultry feeding – *Gallus gallus* [49].

In recent years much attention has been paid to antimicrobial peptides (AMPs) in insects called natural antibiotics due to the increasing global problem of bacterial, fungal, certain parasitic and viral resistance to antibiotics. AMPs mechanism of insect doesn't induce bacterial resistance and involves the destruction of the bacterial cell envelope [50]. However, there are possibilities of using them in agriculture including animal nutrition as well as the pharmaceutical industry [51]. Moreover, insects from the Diptera order, e. g. the larvae of the housefly and black soldier fly have a great ability to utilize organic waste material that contain moisture (60–80 %) converting it to valuable insect protein in such a way that they reduce the accumulation of poultry manure by 50 % and reduce bacterial growth in the manure that results in a reduced odor development and the growth suppression of significant pathogens [41, 52]. Additionally, if insects are used as substitute food sources, they may improve other agricultural sectors and help [45].

Use of insects as protein source for poultry, has been considered [21, 45, 53, 54]. Studies on attitudes towards and willingness to accept insect-based animal feed are generally favorable [55]. Insects as feed stock for poultry can be a sustainable cheaper alternative protein ingredient [6, 7]. Insects are suggested as an alternative protein source in poultry feed, due to similar fat (30–40 % DM) and protein content (40–60 % DM) to that of SBM or FM [21]. By shift to insect meals instead of traditional protein sources like SBM and FM, it may be possible to use natural resources more effectively, reduce greenhouse gas emissions, and prevent the eutrophication of aquatic habitats (loss of nutrients) [56]. Tenebrio molitor larvae meal can be a suitable alter-native protein source for growing broilers also when used as principal protein contributor to the diet [15].

Black soldier fly (BSF), the common housefly maggot, silk worm and several grasshopper species are viable insects for mass rearing [43]. Some like the common housefly maggot have been proposed as poultry feed [57]. They can convert poultry manure into high protein (61 % CP – crude protein) of desirable amino acids composition [58, 59]. A scientific paper [60] demonstrated that BSF (*Hermetia illucens*) larvae meal partially replaced conventional soybean meal and soybean oil in the diets of growing broiler quails. The role of insect in growing chicks and laying hens is reported by different authors (Table 1).

T a b l e 1. **Role of insect in growing chicks and laying hens reported by different authors**

Class of animal	Insect type	Feeding purpose	Result	Recommendation	References
In chicks	BSFL	As component of diet and substitute of soybean meal	Good growth and high feed conversion efficiency	Concentration up to 93 % as significance / above 93 % isn't recommended	Newton et al., 2005
Rural hicken (Ghana and Togo)	Housefly maggot (larvae) meal	Supplementation	Higher growth rate, increased hatchability and clutch size	30–50 g/d/bird	Dankwa et al., 2002, Ekoue and Hadzi, 2000
Laying hens	Meal worm	To replace fishmeal	Higher egg-laying ratio than that obtained with good quality feed	2.4 % and there is limited information	Giannone, 2003
Broiler	Housefly maggot meal	Replacement for conventional protein sources and fishmeal	Have no distinctive organoleptic qualities and to be acceptable by consumers	Inclusion rate is = 10 % in the diet >10 % result lower intake due to darker color of the meal	Awoniyi, 2007
120-day broilers (in Nigeria)	Maggot meal	Mixture of dried cassava peels and maggot meal for replacing 0–100 % maize grain	Cassava peels-maggots' mixture could replace 50 % maize (29 % diet as fed) into save cost	With 4:1 ratio	Adesina et al., 2011
Broiler	Meal worm	For replacing soy meal or fishmeal	Protein quality is like that of soy meal-based broilers. But, low methionine and Ca content for poultry	The addition of 8 % CaCO was found to be suitable to increase Ca	Klasing et al., 2000
Broiler	Meal worm	Inclusion of broiler starter diet based on sorghum and soybean	Without negative effects on feed consumption, weight gain, feed efficiency, texture, palatability or inclusion level	Inclusion level is 25 % mealworm, as a substitution of the basal diet	Ramos Elorduy et al., 2002; Schiavone et al., 2014
Broilers 1–28 days	Grasshopper	As a substitute for fishmeal	Resulted in higher body weight gain, feed intake and feed Conversion	Replace 50 % fishmeal protein with Locust meal 1.7 % in the diet	Adeyemo et al., 2008

The possibility of replacing FM completely or partially with insect meal has been confirmed by generally accessible literature. In example, no adverse impacts on the growth of insect meal-fed chicks have been documented; nonetheless, most papers describe comparable or even better growth rates in chicks when compared to SBM or SBM + FM. In the same way the digestibility of nutrients seems to be unaffected, or at least improved, by the use of insect meal in poultry diet when compared with FM: this is especially true when insect meal has a comparable AAs profile and replaces the whole FM in the diet [9, 61] determining some economical positive effects [62].

Chemical Composition of Different Insects. Insects provide an abundant source of essential nutrients [63]. In a scientific paper [21] observed that insect meals contained varied protein and fat contents even when processed from similar insect species as a result of rearing them on different substrates. Methionine and calcium levels in insect meal are lower (1.0 and 1.5 % respectively) compared to fishmeal [64]. Nutrient concentration of insects depends on their life stage and substrate composition the insects are reared on [21]. Generally, insect meals CP are comparable to that of soybean meal but slightly lower than that in fishmeal. Extracting oil (defatting) from insect meals especially those high in oil is expected to raise the CP content making it comparable to both soybean meal and fishmeal [21].

Chitin is found in the cuticle of insects. Although limited information is available on insect chitin composition, acid-detergent fiber (ADF) and crude fiber (CF) analyses have been used to evaluate the chitin concentration [64]. Cuticle removal increases insect meal digestibility in fish [21]. Insects also have antimicrobial peptides (AMPs). These are natural antibiotics that do not lead to bacterial resistance. In a scientific paper [51] noted that the largest group of insect AMPs are defensing.

T a b l e 2. **Chemical composition of different insects**

Types of insects	Chemical composition					Reference
	CP% (crude protein)	CF% (crude fiber)	EE% (ether extract)	Ash%	GE (gross energy)	
Black solder fly larvae	42.1 ± 1	8	26 ± 8.3	20.6 ± 6	–	St-Hilaire et al., 2007
Housefly maggot meal	50.4 ± 5.3	5.7 ± 2.4	18.9 ± 5.6	10.1 ± 3.3	22.9 ± 1.4	Adesina et al., 2011
Housefly pupae	70.8 ± 5.3	15.7	15.5 ±1	7.7 ± 2.1	24.3	Pretorius, 2011
Meal mealworm	52.8 ± 4.2	–	36.1 ± 4.1	3.1 ± 0.9	26.8 ± 0.4	Finke, 2002
locust or grasshopper meal	57.3 ± 11.8	8.5 ± 4.1	8.5 ± 3.1	6.6 ± 2.5	21.8 ± 2	Alegbeleye et al., 2012
House cricket	63.3 ± 5.7	–	17.3 ± 6.3	5.6 ± 2.4	–	Finke, 2002
Silkworm pupa meal (non defatted)	60.7 ± 7	3.9 ± 1.1	25.7 ± 9	5.8 ± 2.4	25.8	Jintasataporn, 2012

N o t e . Values are mean ± standard deviation and values without SE is when = 1.

According to [65–71], the chemical composition of insects varies between species, growth stage and management conditions and the crude protein (CP%) ranges from 41.1 to 76.1, crude fiber (CF%) from 3.8 to 15.7, ether extract (EE%) from 5.4 to 37.2, ash% from 2.2 to 26.6 and gross energy (GE) from 19.8 to 27.2 (Table 2).

T a b l e 3. **Comparison of some insect's meal with soy meal and fishmeal**

Constituents, % in DM	Housefly maggot meal	Silkworm pupae meal	Black soldier fly larvae	Fishmeal	Soy meal
Cp	50.4–62.1	60.7–81.7	42.1 ± 1	70.6	51.8
Lipid	18.9	25.7	26.0 ± 8	9.9	2.0
Ca	0.47	0.38	5.6 ± 17.1	4.34	0.39
P	1.67	0.60	9 ± 4	2.79	0.69

Source: FAO (Food and Agricultural Organization), 2011 and 2013; Arango Gutierrez et al., 2004; St-Hilaire et al., 2007.

Large Scale Production of Insects. In order to assess the potential of insect use in food and feed, an expert consultative meeting was held in 2012 at the FAO headquarters in Rome. In this forum, large-scale insect rearing was defined as the production of 1 tonne of fresh weight insects per day. Information on rearing conditions and nutrient requirements of insects is a prerequisite for an intensive insect production system. Other important considerations are the adoption of an all-in-all-out system of production and the knowledge of insect diseases, as some species can indirectly affect the natural environment [64]. Rumpold and Schlüter [72] suggest adoption of automated facilities for mass insect production.

Insect species that are viable for mass rearing should have a short life cycle, low disease vulnerability and able to live in high densities within confined space [6, 7]. Such insects include *Hermetia illucens* and *Tenebrio molitor* (Yellow mealworm). The consultative meeting held in Rome recommended that countries in the tropics utilize local species and employ small scale (household production) insect farming while those in temperate parts of the world use cosmopolitan species such as (*Acheta domesticus*) house cricket. Mono specie insect rearing is discouraged while parental genetic line preservation encouraged due to production system vulnerability [6, 7].

Challenges of Insect Rearing and Inclusion in Chicken Feed. In order to sustainably replace soybean and fishmeal (expensive conventional protein ingredients) with insect meal, large quantities of insects will have to be consistently and cost effectively reared (Table 3). Investors intending to set up large scale insect rearing plants are faced with a huge challenge of lack or unclear legal framework on mass-rearing and sale of insects for feed [6, 7]. Some laws like the European Union legislation (Regulation (EC) No. 1069/2009), define insect meal as processed animal protein and therefore the BSE (Bovine spongiform encephalopathy) regulations prohibit its use in livestock feed.

Insect allergens (contact and inhalant allergens) are a risk factor for personnel in the insect rearing industry. Some insects contain anti-nutritious factors: Anaphe specie of the African silkworm pupae contains heat resistant thiaminase [72]. Insect meal shelf life can be prolonged by adding lactic fermented cereal products. The most likely pathogen of processed insect meal spoilage is spore forming bacteria while an easy and favorable method of insect meal preservation is drying [73]. Processing insects into edible insect products has promoted entomophagy in Kenya [6, 7] as it has created some degree of accessibility in a consumer-friendly form.

Conclusion and Recommendation. Based on a number of studies, the inclusion of insect meal in poultry diets lower the cost of feeds without any adverse effects on performance of the chicken, thus contributing to higher profitability of the poultry sector. The costs of conventional feed materials such as SBM and FM are very high in demand and moreover future availability may be limited in poultry nutrition. Due to high nutritional value and global presence, insects are cost effective and considered to be potential sustainable feed resource in poultry nutrition. In general, study findings support the viability of replacing FM with insect meal completely or partially. When compared to SBM or SBM with FM, the majority of papers describe similar or even greater growth rates in chicks. The inclusion of insect larvae meal into the poultry feeding system has both economic and environmental benefits. More effective use of natural resources and reduction in greenhouse gas emissions could be achieved by shift from conventional protein sources like SBM and FM to insect meals. Further research on long-term feeding effects of different insects' meal on egg and meat quality traits and sensory properties and as well impact of insects' meal on intestinal morphology should be conducted thoroughly.

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