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Effective Utilization of Black Soldier Flies Larvae (*Hermetia illucens*) as a Poultry Feed: A Review

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***Abstract*—The use of food that can be consumed by humans as animal feed has become a major problem in today's world. In 2020, one out of every three people will fail to get enough food on a daily basis. Therefore, the carbohydrates, vitamins, and micronutrients essential for physical activity provided by grains have become unavailable in humans. Consequently, it is crucial for the global community to prioritize the development of substitutes for poultry, and other animal feeds. (BSF) The larval stage of this insect offers a remarkable source of protein, presenting a potential path to replace conventional poultry feed derived from grain resources. Research is being conducted on the use of this protein sources, and it is important to solve these problems and produce animal feed that can be obtained by the animal without shortage and at a low cost to the animal keeper. This offers an optimal remedy for countries such as Sri Lanka, which heavily rely on foreign imports for animal feed. This review emphasizes the introduction of the BSF as a means of developing an equitable resolution, not only for Sri Lanka but also for the global population of chicken and other poultry species.**

Keywords*—Black solider fly larvae (BFSL), animal feed ingredient, grains, poultry, Sri Lanka

I. INTRODUCTION

The poultry sector is a fast-growing and flexible industry that is essential for the livelihood of resource-poor farmers. It contributes to improving human nutrition, generating income, and providing manure for crop production. The sector has experienced significant growth and plays a crucial role in the livelihoods of one billion of the world's poorest people [1]. However, in the global economic context, using grains intended for human consumption as animal feed is not a justifiable practice. Approximately one-third of the annual global grain production is designated exclusively for animal feed [2]. The majority of poultry farm owners worldwide continue to use commercial chicken feed without any apparent decrease. In developing countries, large poultry farms are frequently established by feed companies, making them reliant on commercial poultry feed right from the start. This dependence on imported poultry feed or its components become a noticeable economic challenge in resource-constrained regions like Sri Lanka when trying to secure essential nourishment [3, 4]. Instead of depending on imported feeds, it's more cost-effective to create our own animal feed using affordable ingredients. Protein is generally the most expensive feed ingredient in poultry feed. Contemporary poultry feeds primarily comprise grains, soybean oil meal, minerals, and vitamins as protein supplements [5]. Hence, the BSF emerges as an elegant solution to conserve essential grains for the burgeoning global population while furnishing a protein source for poultry [6]. The imperative establishment of a sector centered on BSF larvae -based feed underscores the growing significance of this innovative approach in the animal feed industry. However, to realize its substantial potential, a conducive environment that entails enhanced government support, cost-effective investment, minimized operational expenses, improved regulatory coordination and heightened consumer acceptance is required [7].

The multifaceted utility of the BSF extends beyond its application as an animal feed. This remarkable insect has already been harnessed for organic waste management on a global scale [8], offering substantial potential as a viable solution for addressing the staggering 1.3 billion metric tons of food waste [9]. This helps minimize the negative impacts of such practices, including air and water pollution, land degradation, methane and hazardous leachate emissions, and climate change [10]. Exploring this topic, the aim of this article is to demonstrate how the use BSF can significantly improve the feed supply in the poultry industry.

II. BLACK SOILDER FLY

The BSF, scientifically known as *Hermetia illucens* (Linnaeus, 1758),) (Diptera: Stratiomyidae), is a synanthropic and polysaprophagous insect indigenous to the Neotropics. Over the years, it has undergone extensive global dispersion, extending its habitat to virtually all zoogeographic regions, particularly in warmer climates [11, 12]. BSF belong to the Stratiomyidae family, which encompasses approximately 2700 species [13]. These flies adults characterized by their medium size and predominantly black coloration, with certain body parts displaying can range from combinations of metallic reflective colors such as blue-green [14]. Adults have a compact head, notably slenderer than the body, with widely separated eyes. Its head is shiny black, with a white stripe running along the lower facial region banking the eyes. The dark brown to black antennae have eight segments, with the final segment flattening. The BSF has

a sponge-like, liquid-feeding mouthpart, which is typical of non-biting flies [15, 16, 17]. Male and female adults have unexplored transparent 'windows' on their first abdominal segment. The function of which has not yet been definitively studied, but these may serve several purposes, including thermoregulation and communication, or simply be a result of the structure of its exoskeleton. Adults measure 16-17 mm in length, 2.8-3.8 mm in width and 0.220 g (low) in mass [18]. Sexual dimorphism is evident in Bl, with females typically larger than males. Females display varying patterns on the head and spot sizes on the abdomen. Male genitalia, the aedeagal complex, are slender with basal dilation. Female genitalia have external features known as terminalia, which are characterised by long cerci segmented into two parts (Scissor-like structure). The genital furca exhibits a subtriangular shape with proximal pointed ends, a significant median aperture, and broad, leaf-shaped posterolateral projections [19,20].

III. Importance of BSF In Poultry Feed

An immediate imperative exists for Sri Lanka and the global community to seek alternative sources of animal feed, distinct from traditional grains. The consequence of not doing so may entail a future marked by food scarcity affecting both human and animal populations. This urgency arises not only from population growth but also from the escalating impact of daily worsening weather and climate changes worldwide.

Until recently, eggs were the cheapest source of animal protein available for human consumption in Sri Lanka. However, since 2022, it has escaped the "cheap" label because the price of an egg has increased to Rs.62 per egg since August 2023, and the price of a kilo of chicken has increased to Rs. 1300 [21]. This is a huge amount of money even if you look at the daily expenses of the poor people of Sri Lanka and the common people. The primary factors behind this situation were the insufficient "Maha season" maize harvest in Sri Lanka and the substantial expenses incurred by chicken feed producers' due to maize imports. Consequently, the sharp rise in egg prices, in particular, triggered a significant shift from direct consumption to mass-scale bakery products. This shift, coupled with the subsequent unavailability of the most economical protein source, acted as a catalyst for malnutrition [22].

A. As a High-Protein Poultry Feed.

BSF larval meal emerges as a promising alternative for nutrient-rich and sustainable animal feed, replacing costly and limited protein sources like fishmeal and soybean meal. The insects considered appropriate for animal feed should be capable of large-scale industrial rearing, producing at least 1,000 kg insect fresh weight daily [23]. When quantifying the crude protein content within BSF dried powder (100 g), it is expressed within a specific range, typically falling between 39% and 49% based on research findings [24]. The variability in this range is attributed to the substrate used. According to the available source data, the median crude protein content was approximately 45.01±0.19% [25].

Today, poultry farming mainly focuses on egg-laying hens and broilers for meat production [26]. The protein content in the diet for broiler (Tab. 1) and egg - laying hens (Tab. 2) fluctuate based on their age. A young laying hen typically consumes approximately 100–150g [27] of poultry feed and a five-week-old broiler consumes approximately 1200–1300 g [28]. According to the table data, only approximately 50% of BFS is required to provide the daily protein requirement of chickens.

TABLE 1

Protein requirement [29] of broilers (Ross 308) according to their age and the protein percentage of chicken feed for the respective age in the world [30] and in the Sri Lankan [31] market (100g).	**Age (days)**		
	1 - 10	11 - 24	25 - slaughter
Protein requirement of broiler per day (min %)	22 – 25	21 – 23	19 – 21
Protein content of traditional broiler chicken feed in the global market (min %)	21.95	20.92	19.90
Protein content of broiler chicken feed in the Sri Lanka (min %)	23.0	21.5	19.5

TABLE 2

Protein requirement [32] EU red laying hens, according to their age and the protein percentage of poultry feed [33] for the respective age in the global market (100g).	**Age (weeks)**			
	1 - 5	6 - 10	11 -16/17	18 - 50
Protein requirement of red egg laying breed per day (min %)	2	20	16	18
Protein content of traditional layer chiken feed in the global market (min %)	19.09	17.07	15.38	18.25

B. Supplementing Other Nutritional Needs of Poultry

Apart from proteins, there are also other nutrient and vitamins that are required for poultry [34, 35]. They are also mostly contained in BFSL (Tab. 3).

TABLE 3

Daily nutritional requirements of broiler and laying hens and dry BSFL nutritional value.	**For broilers between 11 and 24 days old**	**for laying hens between 18 and 50 weeks old**	**Dried BSFL powder (100g)**
Crude fibre, % (Max.)	5.00	9.00	8.95
Ash, % (Max.)	2.50	4.00	7.91

Amino acids are crucial for sustaining physiological functions in animals. Some amino acids are categorized as essential because the animal body cannot synthesize them and must acquire them through the diet. These include cysteine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, tyrosine, and valine.

Non-essential amino acids, such as glutamine, glutamate, proline, glycine and arginine, can be synthesized by the animal body from other amino acids. Insect proteins are highly sought after for their well-balanced and adaptable amino acid profiles. BSF represent a promising insect protein source for animal feed. Nevertheless, BSF may lack specific essential amino acids (Methionine + Cystine) and may require supplementation with other protein sources or synthetic amino acids to achieve an optimal balance in diet formulations and fulfill amino acid requirements.

BFSL exhibit an approximate lipid content of 30% on a dry matter basis [36], and this lipid composition varies depending on the specific growth media employed. The utilization of BSF in food waste environments led to a prepupae fatty acid composition prominently characterized by a high concentration of lauric acid. This abundance of lauric acid [37] is notably elevated in larvae cultivated on fruit-based substrates (52%) [38]. Larvae demonstrates the capacity to biosynthesize lipids using the available carbohydrates within the substrate [39]. The protein content of younger larvae, harvested at an early developmental stage, is notably elevated, whereas as the larvae matures, their lipid content proportionally increases [40, 41]. Fatty acids of BSF larvae grown in a fruit substrate medium were as follows: Lauric Acid (C12:0)–76.13, Myristic Acid (C14:0)–8.46, Palmitic Acid (C16:0)–6.98, Oleic Acid (C18:1n-9)–4.97 [42].

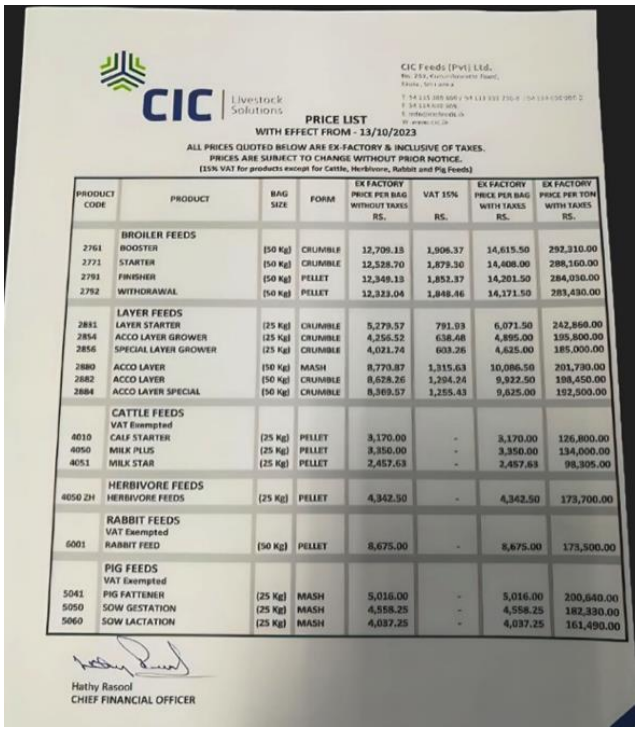
Considering the aforementioned facts, BSF can be recommended as a viable option to supply both macro and micro nutrients while offering it as a preferred feed for poultry. Insect eating is a bird's natural behavior Birds are omnivorous and like to catch and eat more live things. Feeding live larvae to chickens elicits increased feed intake and weight gain due to the larvae's motion capturing the birds' attention [43].

C. The Cost of Poultry Feed Can Be Greatly Reduced

The global poultry feed market, valued at USD 175.9 billion in 2018 with a 4.5% CAGR, is primarily driven by the increasing demand for chicken meat and eggs worldwide. Poultry is an economical source of protein, and its demand is influenced by population and income levels. Packaged poultry feed is growing faster than traditional feed, offering new opportunities.

Quality and pricing of the feed are significant factors. Key players include Cargill, Archer Daniels, Midland, Kemin Industries, and Lallemand, Inc. In the livestock sector, broilers account for over 65% of the market, primarily for meat production, while layers, contributing about 30%, are reared for egg production. High consumption of eggs and population growth drive the layer segment. Regions such as the United States, Mexico, and Canada are prominent markets for poultry products. The diminishment of arable land, water scarcity, fertilizer constraints, climatic perturbations, and geopolitical conflicts will likely exacerbate global grain prices. Consequently, there will be a commensurate escalation in the cost of animal feed.

Due to the increase in the price of animal feed in the Sri Lankan market, the purchase of products made by turning eggs and meat into ingredients has increased. Today, in the Sri Lankan market, layer starter (25 kg)–Rs. 6,071.50, layer grower (25 kg)–Rs.4895, layer special (50 kg)–Rs. 9625, broiler booster (50 kg)–Rs. 14,615.50, broiler starter (50 kg)–Rs. 14,408, broiler finisher (50 kg)–Rs. 14,201.50 (Fig. 1).



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ALL PRICES QUOTED BELOW ARE EX-FACTORY & INCLUSIVE OF TAXES.
PRICES ARE SUBJECT TO CHANGE WITHOUT PRIOR NOTICE.
(15% VAT for products except for Cattle, Herbivore, Rabbit and Pig Feeds)

PRODUCT CODE	PRODUCT	BAG SIZE	FORM	EX FACTORY PRICE PER BAG WITHOUT TAXES RS.	VAT 15% RS.	EX FACTORY PRICE PER BAG WITH TAXES RS.	EX FACTORY PRICE PER TON WITH TAXES RS.
	BROILER FEEDS						
2761	BOOSTER	(50 Kg)	CRUMBLE	12,709.15	1,906.37	14,615.50	292,310.00
2771	STARTER	(50 Kg)	CRUMBLE	12,528.70	1,879.30	14,408.00	288,160.00
2791	FINISHER	(50 Kg)	PELLET	12,348.13	1,852.37	14,201.50	284,030.00
2792	WITHDRAWAL	(50 Kg)	PELLET	12,323.04	1,848.46	14,171.50	283,430.00
	LAYER FEEDS						
2851	LAYER STARTER	(25 Kg)	CRUMBLE	5,279.57	791.93	6,071.50	242,860.00
2854	ACCO LAYER GROWER	(25 Kg)	CRUMBLE	4,256.52	638.48	4,895.00	195,800.00
2856	SPECIAL LAYER GROWER	(25 Kg)	CRUMBLE	4,021.74	603.26	4,625.00	185,000.00
2880	ACCO LAYER	(50 Kg)	MASH	8,770.87	1,315.63	10,086.50	201,730.00
2882	ACCO LAYER	(50 Kg)	CRUMBLE	8,628.26	1,294.24	9,922.50	198,450.00
2884	ACCO LAYER SPECIAL	(50 Kg)	CRUMBLE	8,369.57	1,255.43	9,625.00	192,500.00
	CATTLE FEEDS VAT Exempted						
4010	CALF STARTER	(25 Kg)	PELLET	3,170.00	-	3,170.00	126,800.00
4050	MILK PLUS	(25 Kg)	PELLET	3,350.00	-	3,350.00	134,000.00
4051	MILK STAR	(25 Kg)	PELLET	2,457.63	-	2,457.63	98,305.00
	HERBIVORE FEEDS						
4050 ZH	HERBIVORE FEEDS	(25 Kg)	PELLET	4,342.50	-	4,342.50	173,700.00
	RABBIT FEEDS VAT Exempted						
6001	RABBIT FEED	(50 Kg)	PELLET	8,675.00	-	8,675.00	173,500.00
	PIG FEEDS VAT Exempted						
5041	PIG FATTENER	(25 Kg)	MASH	5,016.00	-	5,016.00	200,640.00
5050	SOW GESTATION	(25 Kg)	MASH	4,558.25	-	4,558.25	182,330.00
5060	SOW LACTATION	(25 Kg)	MASH	4,037.25	-	4,037.25	161,490.00

Hathy Rasool
CHIEF FINANCIAL OFFICER

Fig. 1. Lives stock feed price list October 2023

However, BSFL can save this amount and grow it on wasted kitchen waste and crop residues, thus managing waste and making poultry farming more profitable. In addition, because this larva can be raised in vertical racks in a small amount of space, the production of one type can be developed as an additional source of income for the poultry farmer. It is easy to use because it is not toxic with other foods, and this fly can be found in more countries around the world. Moreover, it is easy for any common poultry farmer to start this business, there is a high demand for BFSL protein in the world market, it can be used to fill the protein needs of humans [44]. BSF has a short life span and large body size, and has very high feed conversion efficiency [45]. Using BSFL is a highly cost-effective approach that has already been successfully implemented. Positive outcomes from these endeavours offer compelling evidence applicable to both developing and developed nations. Indeed, this is a **"Black diamond"** in the animal feed industry.

IV. BSFL Growing Steps for Sri Lanka

Sri Lanka is, classified as a developing nation, as it heavily relies on importing substantial quantities of grain for plant-based protein as animal feed, as elaborated in the fourth section of this article. The protein content typically falls within the range of 10% to 15%, with the highest concentration of protein [46] residing in the storage proteins, such as prolamins, globulins, and germins [47]. Because of that Poultry farmers need to be informed about the potential establishment of BSF as a viable solution to address Sri Lanka's economic challenges stemming from significant expenditures on grain imports from other nations and the resultant surge in egg prices due to escalating costs of chicken feed. It is imperative to emphasize that relying solely on egg imports from India is not a sustainable resolution [48]. When establishing a BSF rearing facility, whether on a large or small scale, the initial step involves the construction of an adult fly rearing enclosure, often referred to as a "mating cage" or "love cage. On a smaller scale, this enclosure can be crafted from materials like wooden framing with a fine nylon mesh [49] covering, meticulously designed to prevent fly escape. Subsequently, it is crucial to introduce female and male flies into the enclosure in a controlled ratio of 40% females to 60% males. This controlled environment promotes successful mating and egg production in a BSF rearing operation [50]. Adult BSF flies do not require solid food; they only require water. To enhance their vitality, providing a water source with a slight sugar solution can be beneficial [51]. It is essential to ensure that the water source is provided in a manner that avoids direct contact with the flies, as any physical disturbance may lead to accidental immersion and mortality in the water. The female BSF typically lays an egg cluster containing 540 to 1505 eggs [52], displaying a distinct yellow-cream colouration. When laying these eggs, the BSF seeks a suitable crevice in close proximity to the organic matter. The eggs are meticulously placed within the Substrate and this process can be aided by using a wooden strip or cardboard.

This process involves the construction of a structure capable of accommodating organic material within a tray. The eggs, measuring approximately 1 mm in length, are incubated for approximately 4 days to produce larvae. During the first four days, these larvae exhibit a cream-white colouration and experience their most rapid growth within an approximately 11–day span. Male larvae typically attain a length ranging between 17 and 18 mm, whereas their female counterparts achieve lengths of 21–23 mm. Their diet primarily consists of organic sources such as vegetables, fruits, fish waste, kitchen scraps, fibrous waste, almond hulls, rice straw, high-moisture feed, and livestock and poultry manure [53]. After the 13 to 18 days good for harvest larvae, this phase referred to as the "prepupae" period. During this preparatory phase, the larvae consume an amount of food equal to twice their body size. Subsequently, the prepupa are subjected to a drying process, which can be achieved through mechanical or high-temperature methods to retain moisture content, ultimately converting them into a powder. This powder can be used for both animal and human consumption, and live larvae can be employed as feed for free-ranging poultry.

Furthermore, scientific inquiries are underway to examine various proportions and formulations of chicken feed blended with BSFL for improved sustainability and resource efficiency in poultry nutrition [54].

V. Conclusion

The use of BSFL (*Hermetia illucens*) as poultry feed presents a promising and sustainable approach to enhance global and Sri Lankan grain preservation for human consumption. As the world faces increasingly dire issues of grain wastage for poultry feeds, such innovative solutions are urgently needed to address the problem. By harnessing the potential of BSFL as alternative protein and nutrient sources for poultry, this strategy not only reduces the pressure on traditional grain resources but also aligns with the imperative to minimize grain wastage. Moreover, this eco-friendly approach underscores the significance of interdisciplinary scientific collaboration, offering a potential blueprint for a more resilient and sustainable future in agriculture and food production. Further research in this area is essential to uncover additional nuances and optimize the utilization of these resources to maximize their impact on grain preservation and food security.

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