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Darboe Abdou Karim
Egerton University, Faculty of Agriculture, Department of Animal Sciences, P.O. Box 536-20115, Egerton, Kenya

Kyarimpa Grace
Egerton University, Faculty of Agriculture, Department of Animal Sciences, P.O. Box 536-20115, Egerton, Kenya

Corresponding Author:
Darboe Abdou Karim
Egerton University, Faculty of Agriculture, Department of Animal Sciences, P.O. Box 536-20115, Egerton, Kenya

A review of non-conventional animal protein sources as poultry feeds

Darboe Abdou Karim and Kyarimpa Grace

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Abstract
The use of non-conventional animal protein (NCAP) sources as alternative feed resources for poultry production has been a topic of interest in recent years. NCAP sources, such as insects, have the potential to significantly reduce feed costs, which account for 80% of total production costs. Insects, in particular, offer protein-rich options with excellent amino acid profiles, resulting in remarkable taste and market value. However, it's essential to consider potential challenges and limitations before implementing these alternatives. One challenge is the lack of regulatory frameworks and guidelines for the use of insects as feed. This can lead to concerns regarding food safety and animal health. Additionally, the cost of production for certain NCAP sources may not be feasible for large-scale commercial operations. Despite these challenges, NCAP sources are a viable option for poultry feed supplementation and should be further explored by the industry. Research has shown that insect meal can be included in poultry diets without adverse effects on performance or carcass quality. Furthermore, using NCAP sources can reduce the environmental impact of poultry production, as they require less land, water, and feed compared to traditional feed sources. In conclusion, using non-conventional animal protein sources, such as insects, can revolutionise the poultry industry by reducing production costs and environmental impact.

Keywords: Animal protein, agro, chicken, non-conventional, performance

1. Introduction

The scarcity of good-quality feed for livestock in underdeveloped nations has resulted in poor animal performance, low growth rates, lower reproductive efficiency, and high morbidity and death rates. This is due to an imbalance between feed availability, feed ingredient prices, and the cost of livestock products such as meat and eggs; there is a pressing need for technology development to expand the use of non-conventional feeds and fibrous agricultural residues (Lebbie *et al*., 1996) [62]. Unfortunately, these feed resources were previously widely disregarded, but they are now more crucial than ever (Chapman and Peres, 2021) [12]. Despite their vast number, animals can be both an advantage and a nuisance because they lack other protein sources. People with low incomes own the majority of low-productive animals; as a result, reducing their number is out of the question to solve this; using non-traditional feed resources may assist in enhancing output. (Duguma & Janssens 2021) [29].

NCFRs are feed sources that have not traditionally been used for feeding livestock and are not routinely used in commercial livestock production. Traditional feeds in tropical climates are primarily drawn from annual crops and animal and industrial sources. NCFR can be considered "new" or "emerging" feed sources. This phrase is increasingly used to describe feed sources such as oil palm by-products, single-cell proteins, and agro-industrial by-products from plants and animals. It may also contain low-quality cellulosic roughage derived from farm waste and abattoir by-products. It can also include those from sugar processing, cereal grains, citrus fruits, and vegetables for human consumption. (Amata, 2014) [2]. Derivatives from chemical or microbiological processes, such as those involved in creating single-cell proteins, can be added to this list. It can be challenging to distinguish between conventional feeds and NCFR. Because it may have been used as livestock feed for a long time, what is currently categorised as NCFR may be conventional feed. One illustration is wheat straw, which is highly popular. Additionally, the type of crops being grown and the current level of crop technology application significantly impact the availability of NCFR, which is primarily of plant origin.

2. Overview of Non-Conventional Animal Protein Sources (NCAP) in Chicken Production

Non-Conventional Animal Protein Sources (NCAP) are rapidly gaining popularity in chicken production due to their exceptional nutritional value and potential for cost savings. NCAP can be sourced from various sources, including insects, fish, and plant-based proteins, with black soldier fly larvae being a common and high-protein NCAP that can replace traditional protein sources such as soybean meal. Despite the potential benefits of NCAP in improving the sustainability of poultry production, it is necessary to acknowledge the challenges and limitations associated with their implementation. Factors such as varying availability and cost based on region and season and regulatory barriers may pose obstacles to using certain NCAP in animal feed. However, given the global poultry industry's challenges, exploring alternative feed resources like NCAP is crucial. Such challenges include disease outbreaks, environmental concerns, and growing demand for poultry products. NCAP use can significantly enhance efficiency and reduce environmental impact, making it a viable and valuable option for poultry producers. Since protein is the diet's most expensive and scarce ingredient, it makes sense for farmers with limited resources to use non-traditional animal protein (NCAP) sources. According to Ncobela and Chimonyo (2015) [37], non-traditional animal protein (NCAP) sources are animal feed used to feed livestock. The protein content of the NCAP sources ranges from 380 to 650 g/kg (Ravindran & Blair, 1993) [46]. The demand for and interest in NCAP has increased. For instance, chickens fed grasshoppers had a preferred flavour and were more expensive on the market than chicks fed traditional protein sources. (Khusro *et al.*, 2012) [28]. This has promoted using NCAP sources as Non-conventional feed supplements for poultry. Additionally, using readily available NCAP sources, these supplements can be given to chickens for free or at a moderate cost. The main factor enhancing chicken nutrition and flock productivity is using NCAP sources. It is essential to avoid depending on the seasonality of NCAP source supplies for both small and big-scale sustainable production (Ncobela & Chimonyo, 2015) [37]. They must be raised, harvested, processed, and stored in sufficient quantities to ensure their safety and availability for use in the future. To support the socioeconomic standard of households with limited resources, facilities utilised for raising, harvesting, processing, and storing NCAP sources should be readily available, hygienic, and affordable, locally recycling, reusing, minimising trash, and feeding these protein sources to chickens, pollution may be decreased (Khusro *et al*., 2012) [28]. Earthworms, locusts, termites, maggots, caterpillars, cockroaches, snails, black soldier grasshopper larvae, and silkworm pupae caterpillars are some resources used as food.

2.1 Earthworms as poultry feed resources

Biological features of earthworm

Earthworms are annelids, which are a type of segmented worm. They are part of the phylum Annelida and are classified as terrestrial or freshwater invertebrates. Earthworms can be a valuable source of nutrition for poultry, providing a sustainable and cost-effective alternative to traditional animal feed. Cultivating earthworms for use as feed requires a suitable medium, such as compost or manure, free from pollutants like heavy metals and pesticides. By controlling for pollutants and adequately processing the worms, you can ensure the safety and health of your birds while providing them with a nutrient-rich food source. Overall, earthworms are essential for anyone looking to provide their poultry with high-quality nutrition in a sustainable and cost-effective way.

The nutritional content of earthworms as poultry feed

Earthworms are a convenient source of protein for poultry feed due to their ability to reproduce quickly and consume various organic wastes. They are beneficial for scavenging hens, as they can offer a valuable source of protein. Earthworms are readily available in wet seasons and swampy areas. However, it is crucial to control the cultivation medium to avoid heavy metal and pollutant absorption by earthworms, which can harm birds that consume them. It's important to note that earthworms are an excellent source of protein and amino acids. Producing them is simple, requiring only mixing materials such as paper, sludge, cardboard, kitchen waste, and sawdust. Despite these undeniable benefits, the use of earthworm meals remains limited in developing countries, as reported by Domnguez *et al*. 2000 [16]. In South Africa, Reinecke *et al*. (1991) [63] conducted a study on the protein quality of three types of earthworms: *Eisenia fetida, Eudrilus eugeniae*, and *Perionyx excavatus*. Their research revealed that *E. fetida, E. eugeniae, and P. excavatus* contain crude protein contents of 66.13%, 58.38%, and 61.63%, respectively, higher than the 61% found in fish meal. Moreover, It is possible for underdeveloped countries with lower labour costs to manufacture earthworm meals. These meals have a similar nutritional profile to other protein sources used in poultry feed, such as fish meals and soybean. Earthworms are abundant in lysine, and their methionine, cysteine, phenylalanine, and tyrosine profiles are also favourable. Additionally, earthworm meal is rich in essential long-chain fatty acids, which contain various vitamins, including niacin (Antonova *et al*., 2021) [6]. Researchers Harwood (I976) [67] conducted the first trials evaluating chicken growth on earthworm protein and found no significant difference in growth when compared to meat meal as a protein supplement. Similar results were also reported by Edwards and Arancon (2004) [17], who found that feeding worms to older birds-maintained egg production. According to Parolini *et al*. (2020) [43], chickens fed earthworms gained weight faster than those fed other diets (including fish meal), had more breast muscle, and consumed less food. Chickens developed well, had a decent mass increase per unit of food, and had excellent nitrogen retention when fed diets containing 72-215 g kg of worm meal. According to Sogbesan and Ugwumba (2008) [52], earthworms have 63.0% crude protein, 5.9% crude fat, 8.9% ash, 0.43% Na, 0.53% Ca, 0.62% K, 0.94% P and 1476 kJ/100 g of metabolisable energy. They also evaluated the essential amino acid content of earthworm meal, which contains 2.83 g/kg of arginine, 1.47 g/kg of histidine, 2.04 g/kg of isoleucine, 4.11 g/kg of leucine, 6.35 g/kg of lysine, 6.26 g/kg of phenylalanine, 4.43 g/kg of tryptophan, and 4.43 g/kg of valine. Finke (2015) [19] reported similar findings. They discovered that earthworm meal included 10.5% crude protein, 0.61% methionine, 0.66% lysine, 0.47% threonine, 0.09% tryptophan, 1.2% crude fat, and 0.6% ash. The primary components of earthworm tissue, soybean meal, fish meal, and insect tissue are shown in Table 1.

Table 1: Composition of the nutritional profile of soybean, fishmeal and earthworm (D.M. basis)

Protein sources	Dry matter	Crude protein	Crude fat	Lysine	Digestible energy M.J./kg
Soybean meal	94%	40-42%	18-22%	2.65%	22.6
Fish meal	92%	56-62%	6-7%	4.085	16.3
Earthworm meal	90%	58-71	5-7%	4.04%	12.46

Parolini *et al*. (2020) [43].

2.2 Maggots as feed resources

Biological features of maggots

Maggots are the larvae of flies and have several distinct biological features, and they are worm-like creatures that are typically white or cream-coloured and have cylindrical bodies with no legs. Maggots have a voracious appetite and feed on decaying organic matter, including animal carcasses and rotting fruits and vegetables. They are also known for their ability to quickly break down and decompose organic matter, making them an essential part of the ecosystem. Despite their unpleasant appearance, maggots have been used in medical settings to help clean wounds and promote healing. Overall, maggots play an essential role in the natural world and have unique biological features that make them both fascinating and valuable.

The nutrition profile of Maggot as poultry feed

Many poultry farmers have found that feeding maggots to their birds is a cost-effective way to provide high-quality protein. Maggots are rich in nutrients, including protein, and are easy to produce using organic waste. By feeding maggots to their birds, farmers can reduce their reliance on expensive commercial feeds while still providing their birds with the essential nutrients they need to grow and stay healthy. It's important to note that while maggots can be a great addition to a poultry diet, they should always be produced safely and hygienically to avoid spreading disease. Maggot can be used as a protein supplement for scavenging village chickens because the chemical and amino acid composition of maggot meal is very high; according to Dankwa *et al*. (2002) [14], chickens treated with 30 to 50 g of housefly maggots increased clutch size, the number of eggs hatched, egg weight, and chick weight. The use of maggots as a protein source has been a significant success. Okah and Onwujiariri (2012) [41] found that chickens fed the control diet gained less weight than those fed 20% and 30% maggot meal. The 40% maggot-feed birds experienced the most significant daily body weight growth. Weight increase for both the starter and grower-finisher phases was significantly higher for the group of birds fed the feed containing the most significant proportion of maggot meal compared to the control group, according to Téguia *et al*. (2002) [55]. Although the difference between the control birds and some diets containing maggot meal was minor, adding maggot meal to the diet resulted in a higher weight increase than the control. Weight increase of all birds utilised in this trial was lower than advised for Arbour Acres grill birds, 1069 g and 1408 g from day old to 4 weeks and 5 to 7 weeks, respectively.

Table 2: Chemical composition of maggot meal (% D.M.)

Chemical characteristics	% D.M.
Dry matter	93.50
Crude protein	61.26
Ash	19.12
Crude fibre	3.58
phosphorus	5.21
ME*	3060.6

Téguia *et al*. (2002) [55]

2.3 Termites as feed poultry resources

Biological Role of Termites

Termites are social insects living in large groups that significantly impact the ecosystem around them. They are essential in tropical ecosystems as they play a crucial role in the decomposition process, nutrient cycling, and carbon processing by feeding on detrital material (Jones *et al*., 2000) [60]. Their ability to utilise and recycle cellulose is crucial to soil formation because of their colossal biomass and numbers. Soil-dwelling termites found in tropical regions also influence soil structure, affecting its properties such as friability, porosity, aeration, organic content, soil permeability, and water storage capacity. The physical and chemical features of the soil and vegetation cover impact termite species composition, diversity, distribution, nesting, and foraging habits (Smith *et al*., 2007) [61]. More than 2500 species of termite have been identified globally (Pearce, 1997) [44], with Africa having the highest transcontinental variety with more than 1000 species (Lewis *et al*., 2003) [30]. More outstanding mound builders, such as Macro-terms pp. up to 5 m high and 12 m broad (Lewis *et al*., 2003) [30], belong to the family Ter-mitidae, and more than 1.800 species have been described, many of which are native to Africa.

The nutritional content of termites as poultry feed

Termites are a significant source of nutrition for poultry. They are rich in protein and other essential nutrients that can help to keep birds healthy and strong. Many farmers have found that incorporating termites into their poultry feed can lead to healthier flocks and increased egg production. Additionally, termites are a sustainable and cost-effective alternative to traditional poultry feed sources. By harnessing the power of termites, farmers can improve the health of their birds and reduce their environmental impact simultaneously. According to various studies and research, incorporating termites into experimental poultry diets has shown promising results. Termites are a rich source of protein, essential amino acids, and other vital nutrients that can help improve birds' overall health and productivity. Farmers who have tried adding termites to their poultry feed have reported increased egg production and better overall health of their flocks. Moreover, termites are considered a sustainable and cost-effective alternative to conventional poultry feed sources, making them an attractive option for farmers looking to reduce their environmental impact. Studies have shown that termites have higher crude protein (70.1%) than soybean meal (43.1%) and fish meal (29.7%), and their metabolisable energy (M.E.) is comparable to maise (16%) and soybean (16.3%), but higher than that of fish meal. Although the ash percentage in termites is lower (8.3%) than in fish meal (41.7%), many researchers believe that termites can replace soybean meal, fish meal, and maise meal-based diets for growing chicks without negatively affecting their growth performance (Moreki & Tiroesele 2012) [34]. replacing soybean meal with termite meal in broiler diets improved the birds' growth performance and feed conversion ratio. Ijaiya & Eko, (2009) [23]. A study finding by Khan *et al*. (2016) [27] reported that feeding laying hens with a diet containing 10% termite meal resulted in significantly higher egg production rates and improved egg quality. These findings suggest that incorporating termites into poultry diets can effectively improve the birds' health and productivity.

In conclusion, termites can be a valuable addition to the experimental diets of poultry. The termite meal diet is high in critical amino acids and contains around 700 g/kg CP and 18 M.J. energy. According to Sogbesan and Ugwumba (2008)

[52], the micro-mineral concentration in termite and housefly larvae was lower than in fish meal. Combining termites with other mineral-rich non-conventional protein supplements, such as earthworms, could solve mineral deficiencies when feeding. For growth, reproduction, defence, and maintenance, these social insects can be divided into physiological units with diverse colony members (Tiroesele & Moreki, 2012) [34]. The colony members, who vary in appearance, have different nutrient requirements for their various jobs and responsibilities.

Table 3: Nutritional composition of termites

Compound	Sogbesan & Ugwumba (2008) [52]	Oyarzun *et al.* (1996) [42]
Crude protein%	46.3	58.20 ±3.67
Crude lipid %	30.1	15.04 ±8.6
Crude fibre	7.3%	-
lignin	-	17.25 ±3.19%
cellulose	-	9.77 ±1.71%
Ash %	3.6	4.11 ±0.23
Dry matter %	96.4	92.36 ±4.32
Gross energy	2457.61 (kJ/100 g)	0.14 ±0.01%
Metabolizable	1843.21 (kJ/100 g)	6.01 ±0.46 (kcal/g)
Digestible energy	3040 /100 g)	-

2.4 Black soldier fly larvae

Biological Roles of black soldier fly larvae

Hermetia illucens (Diptera; Stratiomyidae) is a fly that is native to the tropical and warm temperate zones of America, but it has spread too many other parts of the world (Makkar *et al*., 2014) [31]. It is recognised as a promising candidate for converting food waste into valuable biomass; in reality, BSF larvae may grow on various organic waste and manure and convert it into insect larval biomass that can be used for various uses (Nguyen *et al*., 2015) [39]. Furthermore, these insects have been proven capable of producing bacteriostatic, bactericidal, and fungicidal chemicals, essential in reducing potentially contaminating microorganisms and making these insects exceptionally resistant to various environmental conditions. (Choi *et al.*, 2012; Park *et al.*, 2011) [13, 64]. *Hermetia illucens* (Diptera; Stratiomyidae) have spread too many other parts of the world (Makkar *et al*., 2014) [31]. They can also be used as a source of protein for animal feed and even human consumption. Their ability to efficiently and sustainably convert waste into valuable resources makes them a promising solution for reducing environmental impact and promoting circular economy practices.

The nutritional content of black soldier fly larvae as poultry feed

Black soldier fly larvae are a nutritious and sustainable source of protein for poultry feed. Studies have shown that they contain high levels of protein, beneficial fats, and essential amino acids, making them a valuable addition to the diet of chickens and other birds. Some researchers have found that feeding chickens a diet that includes black soldier fly larvae can lead to healthier and more productive birds. As a result, many farmers and agricultural companies are now exploring the use of these larvae as a cost-effective and environmentally friendly alternative to traditional animal feed. Black soldier fly larvae meal could partially replace fishmeal and soybean meal as a protein source. Huis *et al.*, 2013) [57]. The *Hermetia illucens* L. (Diptera, Stratiomyidae) black soldier fly (BSFL) is one of the insect species regarded as a possible alternative source of protein for animal feed. Black soldier flies larvae are used and recognised as alternative sources of protein for feed of poultry, pigs, and various species of fish and prawns (Osuga *et al*., 2019) [51]. The dry weight of black soldier flies larvae contains up to 50% crude protein (C.P.) and up to 35% lipids. Ndotono *et al*. (2022) [38] found that fishmeal may be substituted with BSFL in chicken diets without having a negative effect on the gut flora or general health of the animals. A study that Mutisya *et al*. reported. (2020) on broiler chicken development performance fed BSFL-Desmodium feed demonstrated that throughout the early growth stages, fishmeal replacement with BSFL-based feed had a substantial effect on average weight gain, daily body weight gain, and average food intake. Similarly, Biasato *et al*. (2020) [9] discovered that including BSFL in the feed positively altered the broiler's cecal microbiota and mucin composition.

2.5 Snail as poultry feed resources

Biological importance of snail

Snails play an essential role in the ecosystem as they help to break down organic matter and recycle nutrients. They are also a valuable feed source for many animals, including birds, mammals, and other invertebrates. Additionally, some species of snails are used in medical research and have been found to produce compounds with potential therapeutic properties. Overall, snails are an important part of the natural world and play a crucial role in maintaining the balance of ecosystems**.** Snails are typically found in river lakes, ponds, swamps, irrigated fields, canals, and wet environments, as they prefer these habitats (Maltby, 2013) [33]. Although they reproduce quickly and grow fast, they can cause harm to crop productivity and are considered a serious pest, particularly for transplanted plants (Maltby, 2013) [33]. Snails have a big appetite for soft, fresh leaves and succulent plants, and they tend to thrive during the rainy season when vegetation is plentiful.

The nutritional profile of snails as poultry feed

Snail flesh is a good source of protein, with a range of 52-63%, similar to a medium-quality fish meal. The ash concentration varies from 11-27% depending on the residual shell material present. Snail flesh has a calcium content of 3-4% and a phosphorus content of 0.4-1.2%. The fat content is usually less than 5%, significantly lower than a regular fish meal. However, it should be noted that snails are considered a severe pest to transplanted plants and can cause harm to crop productivity (Heuzé & Tran, 2017) [20]. Shells consist mainly of mineral substances, with approximately 35% calcium and no residual protein. Snails, in contrast, have a low protein content (14-18% D.M.), a high calcium content (28-31% D.M.), and a low phosphorus content (0.5% D.M. Snails have a spiral-shaped shell and can live on land or in water. In Asia, Africa, and Europe, these sluggish gastropod molluscs serve as a good source of animal protein for people. They are mainly employed as fish feed. (Okafor, 2009) [40]. High levels of fat and C.P. can be found in snail food. Methionine, however, is lacking in it. Chicken performance was improved with snail meal. The maximum relative growth rate of 150.5%, feed conversion ratio of 1.2%, and protein efficiency ratio of 3.7 were observed in fingerling fish given 25% garden snail meat meal. (Sogbesan *et al*., 2008) [52]. Snails can be either cooked or raw. Cooking snails for 15 minutes removes toxic components and facilitates shell removal (Ravindran and Blair 1993) [46]; boiling snails for 5 minutes kills and discards harmful organisms (Ravindran and Blair 1993) [46].

Snail shells can be employed in hens' food as calcium-rich elements (Ncobela & Chimonyo, 2015) [47]. Snails are referred to as snail flesh when the shell has been removed. Snail meat meal is made by sun-drying and grinding snail meat. A kilogramme of washed and unshelled snails yielded 250 grammes of fresh and 100 grammes of dried meat. The protein efficiency ratio of live snails can be stored in water ponds and concrete tanks, respectively. (Ncobela, & Chimonyo, 2015) [47].

2.6 Grasshopper

The biological role of Grasshopper

Grasshoppers play a crucial biological role in their ecosystem as herbivores. They consume various plants, including grasses and leaves, and help control plant growth and maintain a balance in plant populations. Additionally, they serve as a food source for predators such as birds and small mammals. The high protein content in grasshoppers makes them a nutritious meal for these predators. Grasshoppers play an essential role in maintaining the balance and diversity of their ecosystems. They have a unique biological feature called hind legs designed for jumping. These legs are much longer and stronger than their other legs, allowing them to propel themselves up to 20 times their body length in a single jump. This adaptation helps grasshoppers to escape predators and find food and mates. Additionally, grasshoppers have a pair of antennae to sense their environment and communicate with other grasshoppers. These antennae are covered in tiny hairs that detect smells and vibrations, allowing grasshoppers to navigate and avoid danger.

The nutritional profile of Grasshopper as poultry feed

Grasshoppers have been found to be a valuable source of nutrition for poultry feed due to their high levels of lysine, methionine, and cysteine. These amino acids are essential for chickens' growth and development, making grasshoppers a great addition to their diet. Grasshoppers are a sustainable and cost-effective alternative to traditional feed ingredients (A.A., 2021) [1]. Additionally, grasshoppers have high levels of many carotenoids. These carotenoids are sources of vitamin A and may be crucial for insectivores' reproductive and immunological systems and yolk colouration (Finke 2015) [19]. In broiler diets, grasshoppers and locusts were employed, and their usage in layer hen diets would save feed costs and enhance egg quality. (Brah *et al.*, 2017) [11]. Grasshoppers (*Orthoptera: Acrididae*) exemplify a sustainable animal feed supply. Grasshopper meal is poor in amino acids but contains roughly 76% C.P. According to Anand *et al.* (2008) [5], they contain many calories (4.7 to 7Kcal/gm), total fat (6-7.5%), carbohydrate (3.6-7.5%), and minerals. Some minerals and amino acids shortages for grasshoppers imply that feed obtained from these sources should first be supplemented with the limiting nutrients (Khusro *et al.*, 2012) [28]. A favourable amino acid profile, with some more significant amino acids than in fish meals, was observed by Wang *et al.* (2005) [59] in contrast. This variance can be related to grasshopper species, processing, and storage variations. Moreki *et al.* (2012) [34] stated that grasshoppers can be found in Botswana during the hot, dry, rainy, and post-rainy seasons but are not present in the cool, dry season, specifically in June and July. Arbour Acres broiler hens showed improved growth when fed diets with 50% (5%) or 100% (10%) grasshopper meal instead of fish meal. (Amobi *et al.*, 2020) [40]. 2000 broiler chickens were fed grasshopper meal instead of fish meal, which had no negative effects on their growth (Sanusi *et al*., 2013) [49]. The breast and leg muscles of Qinjiaoma broiler chickens fed grasshoppers in a pasture system had higher levels of heme iron, nonheme iron, total iron, and -tocopherol. Additionally, these chickens had higher glutathione peroxidase and superoxide dismutase activities than broiler chickens who were fed differently (Sun *et al*., 2012) [53]. Isa Brown laying hens fed with a diet of 25% grasshopper meal instead of fish meal showed an increase in their Haugh unit. Meanwhile, a 75% grasshopper meal diet resulted in improved egg yolk colour (Amobi *et al*., 2020) [40]. When free-range Qinjiaoma chickens were fed with live grasshoppers and supplementary feed, their live weight increased, along with an improvement in their carcass composition, total lipid, phospholipid, and anti-oxidative potential of meat (Sun *et al*., 2013) [53].

Table 4: Chemical composition of Grasshopper

Parameter	Percentage
Moisture	92.42±0.50
Crude protein	52.50±0.41
Crude fibre	8.30±0.73
fat	27.10±0.80
Ash	4.25±2.10
NFE	5.60±0.20

Moreki *et al*., (2012) [34].

2.7 Silkworm pupal caterpillars

Biological Roles of silkworm

Silkworms play a significant biological role in producing silk, a highly valued textile material. They are the larval form of the silk moth and are responsible for spinning the cocoons that are used to produce silk threads. Silkworms feed on mulberry leaves and undergo several stages of growth and moulting before they are ready to spin their cocoons. The silk produced by silkworms is used in various applications, including clothing, textiles, and even medical sutures. The biological role of silkworms in producing silk has been recognised for thousands of years and continues to be an essential part of the textile industry today**.** Silkworms are the caterpillars of a type of moth that produce silk. The domestic mulberry silkworm, known as Bombyx mori, produces around 90% of the world's silk. This domestic silk moth has been cultivated in China for over 5200 years. (Banday *et al*., 2023) [8]. The life cycle of a silkworm begins when an adult moth lays eggs, which then hatch and grow on mulberry, shea butter, and other leaves for 4-6 weeks until reaching a maximum size of roughly 10 cm. The silkworm then enters the pupal stage and creates a protective cocoon made from unprocessed silk. To obtain 1 kg of raw silk, approximately 8 kg of wet pupae (or 2 kg of dry pupae) must be used after the pupae die through drying, moist heating, or immersion in NaOH before producing their enzymes (Ijaiya & Eko 2009) [23].

The nutritional content of silkworms as poultry feed

Silkworms are a nutritious source of protein for poultry feed. They contain high levels of essential amino acids and are a good source of calcium, phosphorus, and other minerals. Research has shown that incorporating silkworms into poultry feed can improve chickens' and other birds' growth rates and overall health. Proper processing and preparation of silkworms before feeding them to poultry are critical to avoid potential harm to birds from toxins. Laying chickens can safely consume silkworm poultry meals without any negative impact on the silk production process, and there is no evidence to suggest that it causes an opening in the cocoon. (Jintasataporn, 2012) [24]. Sheikh *et al.* (2023) [8] This study compared the effects of replacing soybean meal with silkworm meal (SWPM) at 0%, 25%, 50%, and 100% on-layer chickens' performance. The results showed that the chickens' body weight, feed intake, egg production, egg weight, feed conversion ratio, blood profile, and egg quality were not significantly different between the groups. Therefore, silkworm meals can be considered a viable alternative protein source for layer chickens. In contrast, a previous study by Deshpande *et al*. (1996) [15] found that substituting SWPM for fish meals in diets based on 50-100% silkworm meal lowered feed intake and weight gain. Silkworm pupae are known for their high protein and crude fat content, making them a popular non-conventional animal protein source (NCAP). Khatun *et al*. (2005) [68] found that laying hens with silkworm pupae resulted in a high feed conversion ratio, body weight gain, and egg output percentages. Similarly, broilers fed with silkworm meal showed comparable growth and production performance to those fed with fish meal. Overall, the favourable characteristics of silkworm pupae make them a potential source of protein for animal feed.

2.8 Cricket as chicken feed

The biological role of Crickets

Crickets play an essential biological role in many ecosystems. They are a food source for many animals, including birds, reptiles, and mammals. They also help to break down plant material and contribute to soil health. In addition, crickets are used in scientific research and are becoming a popular source of protein for poultry consumption. Overall, crickets are a valuable and essential part of many ecosystems and have a variety of benefits for both animals and humans**.**

The nutritional content of cricket as poultry feed

The silkworm pupae's high protein and crude fat content make them one of the most well-known NCAP sources. (2012) Jintasataporn. 2009 [24] (Ijaiya and Eko). According to Khatun *et al*. (2005) [68], laying hens fed silkworm pupae exhibited a high feed conversion ratio, high body weight gain, and high egg output percentages. Ijaiya and Eko (2009) [23] found no differences between broiler-fed fish and silkworm meals regarding average daily feed consumption, body weight gain, feed conversion ratio, or protein efficiency ratio. The growth and production performance of the silkworm pupae is favourable, indicating that they have the potential to be employed as a source of protein. The silkworm pupae's high protein and crude fat content make them one of the most well-known NCAP sources. (2012) Jintasataporn. 2009 [24] (Ijaiya and Eko). According to Khatun *et al*. (2005) [68], laying hens fed silkworm pupae exhibited a high feed conversion ratio, high body weight gain, and high egg output percentages. Ijaiya and Eko (2019) found no differences between broiler-fed fish and silkworm meals regarding average daily feed consumption, body weight gain, feed conversion ratio, or protein efficiency ratio. The growth and production performance of the silkworm pupae is favourable, indicating that they have the potential to be employed as a source of protein. (Khan *et al*., 2018) [25].

Table 5: Chemical composition of cricket fishmeal meat and bone meal and soybean

	Ash	Chitin	Fat	Crude protein
Cricket	2.96	8.7	10.3	58.3
fishmeal	12.51	-	4.11	60.2
Meat and bone meal	31.65	-	8.47	48.5
soybean	6.13	-	1.84	46.8

Wang *et al*. (2016) [59]

2.9 Mealworm (Tenebrio molitor) meal

Biological importance of mealworm meal

Mealworm meal is an excellent source of protein and nutrients that can benefit both animals and humans. It contains high levels of essential amino acids, making it an easily digestible protein source. Additionally, mealworm meal is low in fat and cholesterol, making it a healthy alternative to other protein sources. For animals, mealworm meal has been shown to improve growth rates and overall health. It can supplement traditional feed sources, providing animals with a nutrient-rich diet that can support their growth and development. Additionally, mealworm meals can be used as a natural source of protein for pets, such as dogs and cats that may have dietary restrictions or sensitivities. For humans, mealworm meal has the potential to be a sustainable and nutritious food source. It is rich in vitamins and minerals, including iron, calcium, and B vitamins, and can be used as a protein source in a variety of recipes. As the global population grows, finding sustainable and nutritious food sources will become increasingly important, and mealworm meals may be one solution to this challenge. Overall, the biological importance of mealworm meals cannot be overstated. It is a nutrient-rich, sustainable, and versatile protein source that has the potential to benefit both animals and humans**.**

Biological feature of mealworm

The darkling beetle larvae resembling brown worms are called mealworms (*Tenebrio molitor*). Most of the world's population consists of mealworms, which favour warm, moist locations like those found under dead leaves and logs. Mealworms come in three species: the lesser mealworm, *Alphitobius diaperinus* panzer, and the gigantic mealworm, *Zophobas atratus*. According to Selaledi *et al*. (2020) [50], mealworms are in the larval stage of the *Coleoptera Tenebrionidae* (darkling beetles). Mealworms will devour grains, vegetables, damaged food, and other fresh or decaying organic matter because they are made for burrowing and eating.

The nutritional content of mealworm meal as poultry feed

A valuable piece of information that many people are unaware of is that yellow mealworms, commonly referred to as mealworms, can serve as an excellent substitute for traditional protein sources in poultry diets. Extensive research has shown that they possess a high nutritional value that is on par with soybeans and fishmeal. However, it is important to remember that mealworms have limited calcium intake, which can be easily supplemented in their diets. Numerous studies have already been conducted to ascertain the nutritional benefits of mealworms (Finke 2002; Ravzanaadii *et al*. 2012; Bovera *et al*. 2016; Khan *et al*. 2017) [65, 47, 10, 26]. Species and stages of development affect the nutritional value of mealworms. These worms are a good source of polyunsaturated fatty acids and are high in protein, lipids, vital amino acids, vitamins, and minerals. (Rumpold & Schlüter 2013) [66]. In general, insects have higher concentrations of lysine and threonine than do the most widely consumed cereals, such as wheat, rice, cassava, and maise, but lower concentrations of the amino acids methionine and cysteine. However, the excreta and exuvial components were reported to have the highest elements of calcium as compared to larva and beetle (Ravzanaadii *et al*. 2012) [47]. Although mealworm larvae have some phosphorus, they are not a good source of calcium for hens. Relying on mealworms alone may cause calcium insufficiency and metabolic bone disease. Therefore, it is recommended to supplement with calcium when feeding mealworms to hens. In studies involving poultry, adding T. molitor larvae improved the growth of broiler chickens without negatively affecting their carcass traits. This contrasts with some studies that found no significant differences in broiler chicken growth performance and carcass yield (Hong *et al*., 2020) [21].

Table 6: The nutrient profile of dried mealworm larvae from different researchers (% D.M. basis)

Nutrient composition	Khan *et al*. (2017) [26] (%)	Ravzanaadii *et al*. (2012) [47] (%)	Bovera *et al*. (2015) [10] (%)	Hussain *et al*. (2017) [22] (%)
Crude protein	53.0	46.4	51.9	45.8
Crude lipid	3.6	32.7	21.6	34.2
Crude fibre	3.1	4.6	7.2	4.0
Ash	26.8	2.9	4.7	2.5
moisture	-	5.3	-	5.8
Dry matter	-	-	93.9	-
Element				
sodium	-	65	36.4	-
calcium	2.7	7.4	4.3	3.8
potassium	-	14.6	9.4	8.5
Phosphorus	7.8	6.5	7.1	7.0
magnesium	2.3	1.9	2.0	-
zinc	1.2	1.7	1.0	1.0

Selaledi *et al*. (2020) [50].

2.10 Single Cell Proteins (SCP)

The biological role of single-cell protein

Single-cell protein, or SCP, refers to the use of microorganisms as a source of protein for livestock consumption. SCP has been studied extensively due to its potential as a sustainable and efficient alternative to traditional protein sources such as meat and soy. The biological role of SCP lies in the fact that microorganisms are able to convert simple nutrients such as carbohydrates and nitrogen into complex proteins that can be easily digested and utilised by the human body. Moreover, SCP has the potential to be produced on a large-scale using relatively small amounts of resources, making it an attractive option for feeding an ever-growing global population. As research in this field continues, it is hoped that SCP can play an increasingly important role in meeting the nutritional needs of individuals and communities worldwide**.** Single-cell proteins (SCPs) are obtained from unicellular or simple multicellular organisms and are used as food or/and feed supplements. Single-cell proteins are dead, dry cells of microorganisms like yeast, bacteria, fungi, and algae.

Single-cell protein as a poultry feed

SCP is an alternative to common proteins found in animal feed, such as casein, soybean meal, egg protein, and meat protein. SCP is one of the options that is unaffected by climate change. Protein in SCP is abundant and contains all the necessary amino acids. (Bajpai *et al*., 2017) [7]. Single-cell proteins are highly concentrated protein sources, ranging from 50% to 85% in crude protein content. They are rich in usable energy, vitamins, minerals, amino acids, lipids, and carbohydrates, especially in important nutrients like lysine and methionine. These feeds are becoming increasingly popular for their exceptional qualities in poultry production. Yeast was the first microorganism recognised for its value as an animal feed additive around a century ago, and during World War 1, it replaced 50% of the imported protein sources in Germany. The first commercial single-cell protein used as animal feed was protein. However, there is a significant nucleic acid concentration, and the digestibility is lower than that of traditional plant-based protein sources. SCP manufacture is advantageous because it is made from industrial and agricultural waste resources such as molasses, whey, and starch. The microorganism heavily influenced the yield. (Nasseri, *et al.*, 2011) [36].

Table 7: Average different compositions of the main groups of microorganisms (% dry weight)

Composition	Fungi	Algae	Yeast	Bacteria
protein	30.45	40.60	45.55	50.65
fat	2.8	7.20	2.6	1.3
Ash	9.14	8.10	5.10	3.7
Nucleic acid	7.10	3.8	6.12	8.12

Nasseri, *et al.*, (2011) [36]

3. Conclusion

In conclusion, it is essential to consider non-conventional animal protein as a viable option for poultry feed. While traditional protein sources such as soybean meal and fishmeal are widely used, alternative sources such as insects and algae can provide similar nutritional benefits while being more sustainable and environmentally friendly. By diversifying the protein sources in poultry feed, we can reduce our dependence on limited resources and support a more resilient and efficient food system. It is important to continue researching and exploring these options to ensure the health and well-being of both poultry and humans while also minimising our impact on the planet

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