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Review Article

Utilization of Algae Based-Meal as an Alternative Protein Source in Poultry Nutrition: A Review

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Abstract

Feed supply accounts for the majority of chicken production costs, which are estimated to be between 60 and 75 percent. This could lead to a limitation in poultry output because conventional protein and energy sources for concentrate feeds are expensive and scarce. The most well-known traditional plant protein sources for chicken feed are leguminous seeds, cereal grains, soybean and other oil seed meal, and a variety of agro-industrial byproducts. In the current circumstances, it is no longer cost-effective to employ these traditional feed ingredients in chicken feed due to their soaring prices. In order to reduce production costs and increase output and productivity in the poultry business, it is crucial to look for alternate, reasonably priced feed sources that are easily accessible in the region and that are nutritionally equivalent to conventional ones. One way to close a large gap between the availability and demand of conventional feed resources for poultry feeding is to take advantage of the use of non-conventional feed resources (NCFR) in poultry production systems. The use of green algae (Chlorophyta) as an alternative protein source in poultry nutrition is one of the NCFR locally accessible feed resources in Ethiopia. Therefore, the purpose of this paper is to identify some of the most important species of algae that are currently available, as well as their technical applications in the use as poultry feed, as well as their chemical constituents and nutritional values. Additionally, the effects of their inclusion levels on broiler and layer chickens, as well as the quantities and qualities of the products, will be reviewed. Several common algae species, including seaweed, Spirulina platensis, and Chlorella vulgaries, have been covered in this work.

Keywords

Algae Species, Protein Source, Poultry Nutrition

1. Introduction

Finding affordable and alternative feed sources and using locally accessible feed that is nutritionally equivalent to conventional feed are currently pressing issues in the poultry industry. This will help to reduce the cost of producing poultry feed and increase productivity and output [1]. One way to close a large gap between the availability and demand of conventional feed resources is to take the advantage of the use of non-conventional feed resources (NCFR) in chicken nutrition [2]. As a promising source of proteins, lipids, polysaccharides, minerals, vitamins, and enzymes, algae are now used as alternative feed resources to replace conventional feeds [3].

Algae are a broad category of photosynthetic organisms that can include a variety of species. They produce bioactive

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and commercially significant pigments, including astaxanthin, β-carotene and other carotenoids, phycobiliproteins, and chlorophyll [4]. These include carbohydrates, vitamins, minerals, carotenoids, antioxidants, and noteworthy amounts of n-3 and n-6 polyunsaturated fatty acids (PUFA), such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) [5]. As primary producers, algae use photosynthesis to transform carbon dioxide, water, and sunshine into organic matter. As a consequence, this process produces oxygen, which greatly contributes to the oxygen supply on Earth [6].

Based on their color pigmentation, algae can be categorized biologically as Rhodophyta (red algae), Phaeophyta (brown algae), and Chlorophyta (green algae). They are primarily grown in common freshwater environments, such as ponds, pools, lakes, ditches, water tanks, and rivers [7]. Supplementing algal feed has been shown to offer significant effects in boosting energy and protein levels and omega-3 FA in animal products enhancing digestive and overall health. This is a practical way to boost omega-3 FA in their products because monogastric species, like pigs and poultry, are vulnerable to FA changes through dietary manipulation [8].

Dietary supplementation of Spirulina platensis can enhance the immune system of broilers, provide protection against various pathogens, and boost T-cell activity within the body. Different scholars conducted different feeding trial to evaluate the possibility of various microalgal species as an alternative feed protein and their production effects on laying hen and/or health benefits. Microalgae supplementation can enhance egg production, egg quality, and health status [9]. When incorporated into their diet it provides a concentrated source of proteins, vitamins, and minerals. Supplementation of algae improves the hens' nutritional intake resulting in better egg production. The nutrients present in microalgae can stimulate the ovaries and promote the development of larger eggs egg producers to satisfy market demand in need of large size of eggs.

Therefore, the use of macroalgae and microalgae as animal feed, especially in poultry, has been considered a sustainable and promising alternative to face the challenge imposed by conventional feeds. Microalgae production does not require arable land or clean consumable (potable water), thus not competing with human food. Algae are a promising environmentally-friend through the photosynthetic process; microalgae could help mitigate the increase of atmospheric carbon dioxide [10].

2. Algae Based Meal as Alternative Protein Sources in Poultry Nutrition

2.1. Biological Characteristics of Algae

Algae are a class of organisms that are found in a variety of environments, including water (aquatic algae) and land (terrestrial algae). Algae can also exhibit a wide range of shapes, sizes, and habits [11]. Based on their coloration/ pigmentation, the common and widely used algae can be classified as Rhodophyceae (red algae), Phaeophyceae (brown algae), and Chlorophyceae (green algae) [9].

Approximately 350 genera and 2650 species of green algae are currently recognized [12]. A distinctive stellate structure that connects to the flagellar base, double membrane-bound plastids that contain chlorophyll "a" and "b," and accessory pigments present in embryophytes (beta carotene and xanthophylls) are characteristics of green algae, which are photosynthetic eukaryotes. In green plants and green algae, chlorophyll "a" is the green pigment that absorbs light and provides energy for oxygenic photosynthesis, while chlorophyll "b" is the green pigment that collects light energy and converts it into chlorophyll "a" during photosynthesis [13].

2.2. Common Algae Species and Their Nutritional Values

Nowadays, green seaweed (Ulva lactuca and Chlorophyta), Chlorella vulgaris and Spirulina platensis are well known algae species which are commonly used in animal feed supplements. Algae research is a new subject matter of interest for animal nutrition and health because of the variety of algal chemicals present in both macroalgae and microalgae that are advantageous for animal production [14]. From plant-based proteins sources for poultry feed, soybean protein is widely utilized due to its highest protein value. However, there is competitive to be used as human food and poultry feed [3].

Microalgae are being increasingly explored as a valuable and sustainable alternative in animal and poultry nutrition due to high protein contents, and are primary sources of omega-3 fatty acids, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Microalgae contain bioactive compounds that exhibit antioxidant, antimicrobial, and immunomodulatory properties thereby contributing to disease prevention and supporting the immune system [15].

They play a critical role in the environment and ecosystems. They are primary producers meaning they convert sunlight, water, and carbon dioxide into organic matter through the process of photosynthesis. This process generates oxygen as a byproduct contributing significantly to the Earth's oxygen supply. Moreover, algae serve as the foundation of the food chain, furnishing essential nutrients and energy for other organisms such as fish, invertebrates, and whales [9].

2.2.1. Seaweed (Ulva Lactuca)

Seaweeds (macroalgae) are a naturally occurring a good source of biomass that develops in variable environments due to eutrophication. Seaweeds are marine macroalgae which are found along seaside zone and play a role significant in terms of marine ecology and economics [16]. The taxonomic classification of seaweeds will be distinguished in 3 major phyla namely: Ochrophycea (brown algae) having xanthophyll pigment 'fucoxanthin', Chlorophyta (green algae) having dominant chlorophyll pigments ‘a’ and ‘b’ and less xanthophyll pigments; and Rhodophyta (red algae) because of phycocyanin and phycoerythrin pigments [17]. Seaweeds as a rich source of bioactive compounds needed to improve poultry health and performance as well as increase the quality of poultry products (eggs, meat) [18].

Table 1. *Nutritional Contents of Seaweed (Ulva lactuca).*

Categories	Nutrient contents	%DM	Sources
Proteins	Rich in amino acid such as glycine alanine, argine and glutamic acid	18.5-20	Abdullah. [19]
Lipids	Major sources for Polyunsaturated fatty acids (PUFAs) precursor for omega-3 and omega-6	2.3 -3.22	Emin *et al*. [20]
Carbohydrates	Major sources for glycogen	20–76	
	Available	mg/100g	
	Vitamin A	0.5	
Vitamins	Vitamin B_1	5.22	Jingxiang *et al*. [21]
	Vitamin B_2	0.86	
	Vitamin B_9	7.5-5400 µg	
	Iron (Fe)	14-34	Abdullah *et al*. [19]
	Sodium (Na)	351-364	
	Calcium (Ca)	180-1828	Emin *et al*. [20]
Minerals	Potassium (K)	16-26	
	Cupper (Cu)	1.83	Ana *et al*. [22]
	Manganese (Mn)	20-38	

2.2.2. Chlorella Vulgaris

The Chlorella vulgaris strains are species of microalgae that grow easily and quickly. Based on their metabolism and the culture medium they can be autotrophic, heterotrophic, mixotrophic and photo bioreactor (PBR). Chlorella vulgaris has been proposed as a sustainable green feedstock in poultry nutrition due to its ease of cultivation, minimal environmental impact and balanced nutritional composition, high yield of biomass production, and being one of the most produced microalgae worldwide [19]. The various bioactive compounds and nutrients have been reported to promote human health and in animal nutrition [23].

However, Chlorella vulgaris has a recalcitrant cell wall, composed by a diverse and complex matrix of cross-linked insoluble carbohydrates, which are largely indigestible by monogastric animals. Carbohydrate-Active enZymes (CAZymes) have been applied in monogastric livestock as feed additive to hydrolyze the recalcitrant cell wall of the chlorella vulgaris. CAZymes demonstrated the capacity to disrupt microalgae cell walls [20]. Based on indigestibility of chlorella vulgaris, until to date, the majority of the study trials have been carried out with low incorporation rates (<2%) [19].

Table 2. *Nutritional Content of chlorella vulgaris.*

Categories	Contents	%DM	References
Proteins	Threonine, lysine, histidine valine, phenylalanine, methionine, leucine and isoleucine	45-58	Irene *et al.* [24]
Carbohydrates	Major sources for Starch and cellulose	12-55	Bito *et al.* [25]
Lipids	Neutral lipids (mono-, di- and triacylglycerol) polar lipids	5-58	Kun *et al*. [26]

Categories	Contents	%DM	References
	(phospholipids and glycolipids)		
	Available	m/100g	
	Vitamin A	195	Abeer *et al*. [27]
Vitamins	Vitamin B-Complex	40.5-45.6	Tomohiro *et al*. [28]
	Vitamin C	10-100	
	Vitamin E	20-286	
	Calcium (Ca)	972	
Minerals	Potassium (K)	533	Abdel-Wareth *et al.* [29]
	Sodium (Na)	659	
	Magnesium (Mn)	6	

2.2.3. Spirulina Platensis

Spirulina platensis is a multicellular blue-green microalgae and its name derives from the nature of its filaments, characterized by cylindrical, multicellular trichomes. Spirulina Platensis have been used as food, and feed supplement. Spirulina has high quality protein, high amount of polyunsaturated fatty acids (PUFAs), Vitamins and Minerals and diverse ranges of photosynthetic pigmentation including chlorophyll a, xanthophyll, beta-carotene, echinenone, myxoxanthophyll, zeaxanthin, canthaxanthin, diatoxanthin, 3-hydroxyechinenone, betacryptoxanthin, oscillaxanthin [26].

Table 3*. Nutritional Content of Spirulina Platensis.*

Categories	Contents	%DM	References
Proteins	Rich in amino acid such as Histidine, lysine, methionine, tryptophan, phenylalanine, isoleucine and leucine	55-70	Jung *et al.* [30]
Carbohydrates	Major source of glucose along with rhamnose, mannose, xylose, galactose	13.6-14.8	Vatsala. [31]
Lipids	Lienolic acid, precursor of fatty acids for omega-3 and omega-6, Palmitic acid, DHA, Eicosapentaenoic acid, arachidonic acid, and gamma-linolenic acid	6-14.3	Emilia *et al.* [32]
	Available	mg/100g	
	Vitamin A	230	
	Vitamin B complex	12.83	Jung *et al*. [33]
Vitamins	Vitamin C	0.8	
	Vitamin D	12	
	Vitamin E	10 μg	Kulpys *et al.* [34]
	Vitamin K	200 μg	
	Types	mg/100g	
	Iron (Fe)	82.8	Feven *et al*. [35]
Mineral	Calcium (Ca)	1300	Carolin *et al.* [36]
	Magnesium (Mg)	205	

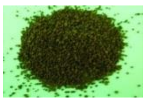
Categories	Contents	%DM	References
	Sodium (Na)	32	
	Phosphorus (P)	118	
	Potassium (K)	930	

2.3. Algae for Sustainable Broiler Production and Meat (Carcass) Quality

Algae have been used in animal feed to increase the omega-3 FA content of animal products. Monogastric animals, such as pigs and poultry, are susceptible to FA changes through dietary modification and this is a viable strategy to increase omega-3 FA in their products [7]. Supplementation of algae up to 4% of seaweed increased feed intake and body weight gain in 1-35 days old of broilers, enhanced nutrient availability and apparent metabolisable energy. However, incorporation more than 10% in diet was observed in significantly decreased feed intake and growth rate in both adult cockerels and 1-21 day-old broiler chicks [14]. Supplementation of algae sourced meal in broiler diets can improve the production performance and meat quality characteristics. Algae is recommended as feed additives due to their high levels of macro-and micro-elements and ability to improve the growth performance and feed efficiency of broilers, owing to the properties of seaweed polysaccharides that can increase the health and productivity of chickens [15].

Dietary supplementation of Spirulina platensis, can enhance the immune system of broilers, provide protection against various pathogens, and boost T-cell activity within the body. Dietary supplementation of Spirulina at 10g/kg of diet showed significantly higher body weight gain and, consequently, linear improvements in FCR was observed in Cobb broilers during 35 days experimental period dietary supplementation with 1% or 2% DHA-rich microalgae significantly increased body weight gain and improved feed conversion of broilers [8]. Table 1 shows a variety of feeding effects on growth performance and meat yield broilers fed different levels of various species algae were added to broiler diets [7].

Table 4. Dietary Supplementation of Algae on Growth Performances and Meat Quality of Broiler.

Algae Species	Products	Levels%	Effects	References
Seaweed (U. Lactuca)		3-6	Improvement in feed I intake and live body weight gain birds received up to 6% recorded	Izabela and Khalid. [38]
Chlorella vulgaris		0.1	Enhanced growth Performance, decreased microbial growth in breast muscle, malondialdehyde and protein carbonyl levels, cooking loss, and aerobic plate count, and boosted superoxide dismutase activities in breast muscle.	El-Shall *et al.* [7]. Iulia *et al*. [33]
Spirulina platensis		0.25-1.0	Enhanced growth performance, carcass and meat yields, oxidative stability, and fatty acids modulation	Swat *et al.* [34]
Spirulina platensis		6, 11, 16, 21	Show similar result in performance as in control group but improved of on the methionine content digestibility	Boskovic *et al.* [37]
Spirulina platensis		1.5- 2	Positive effects on feed intake and live body weight gain	Kulpys *et al*. [38].

2.4. Algae for Sustainable Layer Performances and Egg Quality

2.4.1. Algae for Layer Performances

Different scholars conducted different feeding trial to evaluate the possibility of various microalgal species as an alternative feed protein and their production effects on laying hen and/or health benefits. Microalgae supplementation can enhance egg production, egg quality, and health status [39]. Supplementation of algae improves the hens' nutritional intake resulting in better egg production. The nutrients present in microalgae can stimulate the ovaries and promote the development of larger eggs egg producers to satisfy market demand in need of large size of eggs [40]. Laying hen fed Spirulina platensis (1.5-2.5%) and Chlorella vulgaris (2.5–7.5%) diets increased egg production rate (from 85 to 91%) and egg weight (from 62.8 to 64.3g) [7].

Dietary algae supplementation for Hy-Line Brown layers with 2% of Chlorella vulgaris increased egg productivity from 55.4% in the control to 59% in the supplemented group. Supplementing the same diets for 22to 36 week-old Lohmann Brown hens with 0.5% of the same microalgae increased egg weight from 58.9g by 60.4 g for the control group.

2.4.2. Algae for Egg Quality

Other studies have shown a positive effect with algae supplementation, whereby yolk colour has become more yellow by feeding of 63- to 67-week-old Hy-line W 36 hens. The strength and quality of eggshells are the two egg quality attributes in preventing egg breakage during handling and transportation. Microalgae are good sources essential nutrients like calcium and phosphorus used to enhance eggshell quality. These nutrients play a vital role in the formation and maintenance of strong eggshells reducing the risk of egg breakage [41].

Use of Spirulina the diet) as chicken feed has already demonstrated improved yolk color in eggs. Microalgae contain natural pigments such as carotenoids which contribute to the vibrant yellow-orange yolk color. In addition, the levels of cholesterol and triglycerides in eggs were significantly decreased by supplementation of Spirulina in laying hen's diet compared to control [42].

Supplementation of microalgae feed decrease the levels of cholesterol and triglycerides in eggs were significantly decreased [40]. Supplementation of algal biomass (1 to 5%) to laying hens diet has been shown to improve DHA concentrations in eggs. Omega-3 fatty acids are highly beneficial for human health and their presence in eggs is a desirable quality. Microalgae are an excellent source of omega-3 fatty acids such as EPA and DHA [25].

Table 5. Dietary Supplementation of Different Microalgae on Egg Production and Quality.

Algae species	Levels%	Effects	References
Spirulina platensis	1.5-3, 4-6, 8-12	Decreased cholesterol and triglycerides and improves egg laying performance and quality	Ahammed *et al.* [9].
Chlorella vulgaris	2	Enhanced yolk carotenoids lutein, B-carotene, and zeaxanthin concentration and egg color score in chickens	Thapa. [40]
Seaweed (U. Lactuca	4	Increased HDEP% from 55.4%(control) to 59%) supplemented group)	Martins *et al.* [41]
Chlorella vulgaris	1- 10	Improve Feed intake and increased daily egg production rate and egg mass Improve egg quality in terms of Haugh unit score and yolk color	Salahuddin *et al.* [42]
Spirulina platensis	1.5-3	Egg yolk become deep yellow	Peipei & Sumin, [43].

2.5. Eco-Friendly and Algae Production System

The cultivation/production of algae can be carried by two main production approaches namely: open-pond systems and closed-loop systems [43].

2.5.1. Open Pond Algae Production System

Open pond production system utilizes large outdoor ponds where algae are cultivated consuming natural sunlight and defined nutrient-rich media or sewages by applying wisely management of environmental conditions such as temperature, pH, CO_2 and nutrient levels to ensure optimal algal growth. Due to their shallow and broad surface area, open pond system of algae production are designed to maximize surface area and sun exposure sunlight, so they're spanning of many acres [44].

Raceway ponds are a popular configuration, where the water flows through an endless loop, similar to a racetrack. Open ponds can produce algae for nutritional products, biofuels, and chemicals. Open ponds are also preferred for activities like treating wastewater. They have simple structure of ponds and minimal equipment means low capital investments for construction, operation and maintenance. Open ponds can be established on low-value land that's not suitable or desirable for agriculture or development. It requires minimal trained manpower. Algae grown in open ponds are high in oil contents [45].

2.5.2. Closed-Loop Algae Production System

Closed-loop algae systems, on the other hand, employ controlled environments such as photo bioreactors. These systems provide precise control over environmental parameters, allowing for consistent and efficient algae cultivation. Closed systems include systems like photo bioreactors (PBR) where algae is contained in some sort of transparent vessel and supplied with CO_2. Closed systems reduce invasion by unwanted strains of algae and hungry zooplankton [46].

They're particularly valuable where growing conditions must be closely managed in ways that are impossible for open ponds, but they're complex, artificial environments and are much more expensive to build and maintain. There are considerable differences between these two systems as far as capital as well as operational costs of production are concerned [49]. By utilizing waste nutrients for algae production, this method embodies the principles of a circular economy, transforming potential environmental liabilities into valuable agricultural inputs. Highlighting the eco-friendly production of algae not only emphasizes its role as a sustainable feed component but also aligns with global sustainability objectives [47].

2.5.3. Production and Processing of Algae Products for Poultry Meal

Algae can be produced and processed using various productions methods and processing procedures such as: extraction, drying, and storage of the algae products for poultry feed ingredients. First the algae may be grown in outdoor ponds, then collected and passed through a series of cleaning screens, and spray dried to remove the moisture, resulting in a dry algae product. Because of their chemical composition, microalgae as well as macroalgae can be efficiently used in poultry nutrition to enhance the pigmentation and nutritional value of meat and eggs, as well as partial replacement of conventional dietary protein sources [48].

2.5.4. Toxic Metabolites Producing Algae

Most microalgae species, especially cyanobacteria, produce a variety of toxic substances, generally called cyanotoxins. Cyanobacterial harmful algal blooms (cHABs) often dominated by Microcystis spp. are increasing in frequency and severity globally, with further increases predicted coincident with climate change [44]. Microcystin aeruginosa is the dominant microalga of the bloom-secreting microcystins, which have been reported to be lethal for animals and humans. Different types of microcystins have been identified. The microcystins are hepatocyclic peptides with a C20 amino acid chain, which determines the degree of toxicity. Studies have shown that cyanobacterial toxins can treat tumors [50].

3. Conclusions and Future Concern

Poultry feed accounts over 60-75% production cost for feed demand and supply. However, the dynamic change and rise of poultry feed prices is becoming a bottle neck for poultry producers and there is a need arises to replace the conventional poultry feed by new searching alternative nonconventional locally available feed resources.

The non-conventional feed resource (NCFR) in poultry production is one of the alternative feed resources reducing the gaps that arise between the supply and demand of conventional poultry feed resources. One of the NCFR locally available feed resources in Ethiopia is utilization of green Algae (Chlorophyta) as an Alternative Protein Source in Poultry Nutrition.

Algae (microalgae and seaweeds), offer a rich source of nutrients that can potentially revolutionize poultry diets, leading to improved growth performance, enhanced nutrient utilization, and overall health benefits for chickens. The rich nutritional profile of algae offers a plethora of benefits, spanning from improving growth performance and egg production to enhancing the quality of poultry products such as meat and eggs. Algae's abundance of proteins, lipids, vitamins, and minerals provides an all-inclusive approach to enhancing broiler and hen health.

The future concern is on the studies should aim to determine the optimal inclusion rates of algae in chicken diets at various production phases, including starter, grower, and finisher stages. However, the journey towards fully integrating these algae into poultry diets necessitates comprehensive research to evaluate their health benefits, optimize cultivation techniques further assessing and evaluating their economic feasibility within the poultry industry.

Abbreviations

DHA	Docosahexaenoic Acid
DM%	Dry Matter
EPA	Eicosapentaenoic Acid
FAs	Fatty Acids
HDEP%	Hen Day Egg Production
NCFR	Non-Conventional Feed Resource

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Availability of Data and Materials

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Author Contributions

Seyoum Bekele Alemu, the first author generated the primary data, manipulated, and organized. Biazen Abrar (PhD, Assistant Professor of Tropical Animal Production) the correspondence author, designed the manuscript for publication format, translated, corrected the English language grammar.

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Conflicts of Interest

The authors declare no conflicts of interest.

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