ALTERNATIVE SOURCES OF PROTEINS IN FARM ANIMAL FEEDING

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ABSTRACT
The global demand for protein is on the rise owing to the exponential increase in the world population and to meet the global protein requirements, it is imperative to seek alternative sources of proteins in farm animal feeding. Recognizing the importance of proteins and the fact that a major portion of human protein requirements is derived from livestock in the form of meat, milk, and eggs, the available protein-feeding stuff in the form of soybean meal cannot be regarded as sufficient for feeding to livestock. Oil seeds such as rapeseed meal and canola meal have a crude protein content of 30%-40% and are widely used and hence a potential alternative protein source to soybean meal. Going forward, Grain legumes such as peas, faba beans, and lupins, another alternative source of proteins have the potential to replace traditional protein feeds completely or partially such as bone and fish meals. Duckweed with a protein content of 20%-45% is another plant-based potential protein source that can be employed in livestock feeding particularly pigs owing to its huge potential as a growth promoter as evidenced by studies in pigs and piglets. Because of their nutritional qualities and possible environmental advantages, insects represent another class of alternative protein sources that have enormous potential to function as sustainable protein sources. Several insect species have been assessed for use as animal feeds; the most promising ones include the yellow mealworm (Tenebrio molitor, TM), the common house fly (MD), and the black soldier fly (Hermetia illucens, HI). Byproducts from aquaculture and fisheries are abundant in macro- and micronutrients, and their utilisation can provide fishmeal and fish oil, which can then be further adapted for use as a source of protein in animal nutrition. Employing microalgae as an alternative source of protein in animal feeding is somehow a new concept. Many nutritional and toxicological studies have demonstrated the potential of algae biomass as a valued feed supplement or substitute for conventional protein sources such as soybean meal. While these alternative protein sources in livestock feeding may serve as useful tools, parameters such as feed safety and acceptability should be monitored based on feed safety regulations.

Keywords: Protein, Farm Animal, Legumes, Insects, Single cell protein, Yeast, Duckweed

INTRODUCTION
Farm animals, their products, and byproducts have been essential in improving human health and farm span for centuries, providing major contributions to the human diet, clothing, labour, medicine, and research (Kues & Niemann, 2004). Milk, meat and eggs are the principal animal food products, and currently account for around 13% of the energy and 28% of the protein consumed globally; in industrialised countries, this climbs to 20 and 48% for energy and protein, respectively (FAO, 2009). The primary goals of livestock breeding are to achieve long-term development in livestock production and so meet the population's food requirements. Improving animal and poultry productivity through the provision of balanced and complete feeds is an important strategy to increase the impact of livestock (Nikolaev, Karapetyan, Shkalenko, Zabelina, & Struk, 2008). At present, insufficient fodder base and unbalanced diets in terms of lacking potential nutrients are the key contributors towards the low efficiency of agricultural animals and poultry (Sankina, Chernysh, & Sankin, 2017). Since a major portion of the human protein requirements are being met from animal products such as meat, milk, and eggs, and as the population is rising globally, the demand for animal-origin proteins is also rising in parallel. Animal products serve as a vital source of protein, with 59% of the total consumed protein in the European Union (EU) being derived from animal products (de Visser, Schreuder, & Stoddard, 2014). Like human beings, animals require an uninterrupted supply of feed rich in protein and energy to yield significant food products of human importance. The scarcity of available feed resources and the increasing costs resulting from economic reforms in the agricultural sector are the main barriers to increasing livestock and cattle breeding production (Penkova & Mishina, 2012). Proteins are essential nutrients for farm animals consisting of building blocks of amino acids that play an important role in growth, production maintenance, and reproduction. The traditional sources of proteins for farm animals are comprised of Soyabean, Canola meal, and Corn gluten meals. The protein shortage is a global concern, and substantial research into new sustainable protein sources is undertaken (Gasco et al., 2020). It is predicted that the world may soon face a shortage of Human-Edible Protein sources (HEP) for livestock production. HEP refers to plant-based feed sources that are both nutritious and valuable enough to be directly consumed by humans. Since both humans and livestock rely on these resources, creating competition. Livestock feed consists of mixture of HEP and Human Inedible Protein (HIP) elements, including by-products derived from the food industry. Proteins are essential for the development, maintenance, and proper functioning of cells, tissues, and organs. They also provide energy during times of severe malnutrition or extreme exercise conditions (WAGENMAKERS, 1998). The sustainable development of the animal production sector needs alternative protein sources for feed formulation. Keeping in view the predicted protein shortage challenges, this review focuses on identifying the potential sources of alternative and new proteins for livestock feeding, their accessibility, safety, and acceptability.
ALTERNATIVE SOURCES OF PROTEINS IN FARM ANIMAL FEEDING

Oil seeds

Duckweed is becoming more popular as people look for substitute protein sources for soybean meal in animal feeds. Since the 1960s and 1970s, this well-known plant has been used in Poland as a source of feed for pigs and ducks (Soita, Rekiel, & Batorska, 2019). One of the noteworthy characteristics of duckweed is its potential as a source of proteinaceous food, with several species having a suitable profile of essential amino acids (Table 2) (Rusoff, Blakney Jr., & Culley Jr., 1980). The dry matter composition of duckweed varies from 3% to 14%. The quality of the growth media affects not only the protein content but also the other elements. Protein content in dry matter can vary from 7% to 45%, with 20% to 45% being the most typical range. There is a range of 2% to 9% for fat content, 12% to 28% for fibre content, and 14% to 44% for carbohydrates (Leng, 1999). Research has shown that when fed duckweed, piglets showed significant increases in body weight and feed consumption. Piglets in growth showed no reluctance to eat diets based on duckweed. It was discovered that the piglets fed 40 and 60% duckweed had daily body weight gains higher than those of the control group, which was fed soybean as the only source of protein. The animals receiving the longest-term highest dose of duckweed had the greatest body weight rise, indicating that the effects on body weights were significant (Moss, 1999). Fresh duckweed supplementation (about 1.5 kg/day/animal) improved body weight gain indicating that the effects on body weights were significant (Leng, 1999). Along with its chemical makeup, duckweed’s potential use as bovine feed has also been investigated. It was...

**Figure 1 Alternative sources of proteins for farm animals feeding**

Rapeseed meal or Canola meal is an alternative to soybean meal that can be used as a potential source of protein in animal nutrition. These oil seeds are widely used as protein sources for various animal species such as poultry, pig, cattle, and fish around the world (Enami, 2011). The crude protein content of the meal ranges from 30% to 40%, depending on the extraction method used (ELSAYED, 2019). However, one of the limiting factors for incorporating rapeseed meal as a substitute protein source is the presence of its antinutritive compounds, particularly glucosinolates, which have detrimental effects in poultry and pigs. Plant breeding can help reduce the glucosinolate content in certain plant varieties. Some varieties with low glucosinolate content are available. For monogastric animals, the maximum concentration of glucosinolates in their feed should be less than 12,000 mg/kg of whole seed and less than 20,160 mg/kg of extracted meal (Tripathi & Mishra, 2007). Sunflower meal is another rich source of protein but due to its high phytotoxic content, particularly chlorogenic acid, the availability of proteins is impaired (González-Pérez et al., 2002). Extracted cottonseed meal is also an alternative to soybean meal, but the associated drawback is that in certain countries there are only genetically modified varieties available, with protein concentrations largely depending upon the variety and the mode of extraction but typically varying from 30-50% (ELSAYED, 2019). Sunflower meal also serves as an alternative source of protein but its high content of phytins, particularly chlorogenic acid affects the protein availability (González-Pérez et al., 2002).

**Legume seeds**

Legumes like peas, faba beans, and lupins serve as valuable protein and energy sources for monogastric animals. They offer a viable alternative to conventional animal-derived protein sources such as meat and bone meal or fish meal. Moreover, they present an alternative protein-rich option compared to soybean meal (SBM) and other oilseed meals. Integrating grain legumes into animal feed formulations helps to ensure a nutritious and well balanced diet for livestock (Jezierny, Mosenbín, & Bauer, 2010). The search for alternative protein sources has spurred a rising interest in the utilization of grain legumes, given their pivotal role as a valuable plant-based protein source. Additionally, grain legumes are also cultivated as a nitrogen-fixing crop in rotation systems (López-Bellido, López-Bellido, & López-Bellido, 2005). In Europe, major grain legumes include peas, faba beans, and lupins whereas Soybeans production leads in Argentina, Brazil, China, India, and the United States (Karr-Lilienthal, Grieshop, Merchel, Mahan, & Fahey, 2004). Cultivating peas in cool seasons is a good alternative for regions unsuitable for growing soybeans due to their sensitivity to low temperatures. Peas can withstand low temperatures for germination and growth because they are less susceptible to frost (Miller et al., 2002). Although peas are mostly grown for human consumption, they are becoming more popular in the northern United States, Canada, and Australia as pig feed (Blair, 2017). Cultivated species of Lupins being used as feed ingredients in ruminant, pig, and poultry nutrition include Lupinus angustifolius, Lupinus albus, and Lupinus latuus with all of them originating from the Mediterranean region (van Barneveld, 1999). Among the grain legumes, the crude protein content of lupins is the highest (324-381 g/kg dry matter (DM)) as compared to faba beans (301 g/kg DM) and peas (246 g/kg DM). The Crude protein content and level of amino acids in different grain legumes are given in Tab. 1.

**Duckweed (Lemna minor)**

Duckweed is becoming more popular as people look for substitute protein sources for soybean meal in animal feeds. Since the 1960s and 1970s, this well-known plant has been used in Poland as a source of feed for pigs and ducks (Soita, Rekiel, & Batorska, 2019). One of the noteworthy characteristics of duckweed is its potential as a source of proteinaceous food, with several species having a suitable profile of essential amino acids (Table 2) (Rusoff, Blakney Jr., & Culley Jr., 1980). The dry matter composition of duckweed varies from 3% to 14%. The quality of the growth media affects not only the protein content but also the other elements. Protein content in dry matter can vary from 7% to 45%, with 20% to 45% being the most typical range. There is a range of 2% to 9% for fat content, 12% to 28% for fibre content, and 14% to 44% for carbohydrates (Leng, 1999). Research has shown that when fed duckweed, piglets showed significant increases in body weight and feed consumption. Piglets in growth showed no reluctance to eat diets based on duckweed. It was discovered that the piglets fed 40 and 60% duckweed had daily body weight gains higher than those of the control group, which was fed soybean as the only source of protein. The animals receiving the longest-term highest dose of duckweed had the greatest body weight rise, indicating that the effects on body weights were significant (Moss, 1999). Fresh duckweed supplementation (about 1.5 kg/day/animal) improved body weight gain and produced a better carcass output with more lean meat and less fat and bones (Hang, Linh, Everts, & Beynen, 2009). Along with its chemical makeup, duckweed's potential use as bovine feed has also been investigated. It was...
discovered that the proximate composition of the three main varieties of duckweed—Spirodela, Lemna, and Wolffia—varies. Duckweed's dry matter and crude protein are highly degradable in the rumen, according to the evaluation of the rate and extent of digestion. For this reason, it's important to determine the level of duckweed supplementation in cattle feed (Hueque, Choudbury, & Kibria, 1996).

Experimental trials have also been conducted regarding the supplementation of duckweed as a potential source of protein in small ruminants and revealed that nutritionally duckweed is comparable to soybean meal with no adverse effects on ruminal pH, ammonium ions concentration, and the amount of volatile fatty acids (Reid Jr., 2004). However, despite its great potential as an alternative protein source for farm animals and aquaculture, its use is limited owing to its difficult harvesting in some climatic zones and the costly production of processed feed (Soifita et al., 2019).

**Table 2** Amino acid composition of important species of Duckweed (g/100 g)

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>L. gibba</th>
<th>S. polyrhiza</th>
<th>S. punctata</th>
<th>W. columbiana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alanine</td>
<td>4.59</td>
<td>4.48</td>
<td>4.79</td>
<td>3.75</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.89</td>
<td>2.15</td>
<td>1.90</td>
<td>1.18</td>
</tr>
<tr>
<td>Aspartic</td>
<td>7.12</td>
<td>7.55</td>
<td>7.38</td>
<td>5.63</td>
</tr>
<tr>
<td>Glutamic</td>
<td>7.60</td>
<td>8.00</td>
<td>7.69</td>
<td>5.76</td>
</tr>
<tr>
<td>Glycine</td>
<td>3.79</td>
<td>3.95</td>
<td>3.93</td>
<td>3.04</td>
</tr>
<tr>
<td>Arginine</td>
<td>4.29</td>
<td>5.25</td>
<td>4.86</td>
<td>3.78</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>3.87</td>
<td>3.75</td>
<td>3.76</td>
<td>3.06</td>
</tr>
<tr>
<td>Leucine</td>
<td>7.15</td>
<td>6.85</td>
<td>6.88</td>
<td>5.83</td>
</tr>
<tr>
<td>Lysine</td>
<td>4.13</td>
<td>4.30</td>
<td>4.26</td>
<td>3.37</td>
</tr>
<tr>
<td>Valine</td>
<td>4.96</td>
<td>4.40</td>
<td>4.71</td>
<td>3.49</td>
</tr>
<tr>
<td>Phenylnaline</td>
<td>4.45</td>
<td>4.20</td>
<td>4.38</td>
<td>3.60</td>
</tr>
<tr>
<td>Threonine</td>
<td>3.20</td>
<td>3.45</td>
<td>3.31</td>
<td>2.55</td>
</tr>
<tr>
<td>Serine</td>
<td>2.61</td>
<td>2.80</td>
<td>2.83</td>
<td>2.28</td>
</tr>
<tr>
<td>Proline</td>
<td>2.93</td>
<td>3.38</td>
<td>2.95</td>
<td>2.41</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>2.91</td>
<td>3.05</td>
<td>3.14</td>
<td>2.17</td>
</tr>
<tr>
<td>Methionine</td>
<td>0.83</td>
<td>0.83</td>
<td>1.07</td>
<td>0.87</td>
</tr>
</tbody>
</table>

(Rasoff et al., 1980)

**Table 3** Summary of Growth Responses in Pigs Diet containing insects

<table>
<thead>
<tr>
<th>Pig Age</th>
<th>Insect species</th>
<th>Feed inclusion level</th>
<th>Growth responses</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 weeks</td>
<td>BSF</td>
<td>33%</td>
<td>Increased feed intake; reduced apparent DM digestibility</td>
<td>(Newton, Booram, Barker, &amp; Hale, 1977)</td>
</tr>
<tr>
<td>Early weened pigs</td>
<td>BSF</td>
<td>0%, 50% or 100% replacement of dried plasma</td>
<td>50% diet improved performance; 100% diet increased percentage</td>
<td>(Newton, Sheppard et al. 2005)</td>
</tr>
<tr>
<td>Weened pigs</td>
<td>Mealworm</td>
<td>0%, 1.5%, 3%, 4.5%, and 6% replacement of soybean meal</td>
<td>Linear increase in BW, ADG, ADFI, DM and CP digestibility</td>
<td>(Jin, Heo, Hong, Kim, &amp; Kim, 2016)</td>
</tr>
<tr>
<td>Weened female pigs</td>
<td>BSF</td>
<td>0%, 30% and 60% replacement of soybean meal</td>
<td>Linear increase in ADFI, No effect on growth</td>
<td>(Bisazza et al., 2019)</td>
</tr>
<tr>
<td>Barrows</td>
<td>BSF</td>
<td>50%, 75% and 100% replacement of soybean meal</td>
<td>No effect on base meat quality measures, increased juiciness, higher backfat PUFAs contents</td>
<td>(Altmann, Neumann, Rothstein, Liebert, &amp; Mörlein, 2019)</td>
</tr>
</tbody>
</table>

BSF= Black soldier fly; ADG-Average daily gain; ADFI-Average daily feed intake; PUFAs-Polyunsaturated fatty acid. Table adapted from (DiGiacomo & Leury, 2019).

**Pig diets** that use waste-reared larvae instead of soybean meal reduces land usage and global warming, but the resulting life cycle evaluation generates contradictory results (van Zanten, Bikker, Meerburg, & de Boer, 2018). However, the legal implications of incorporating insects in animal diets vary from region to region as summarized by (Lahteenmaki-Uutela et al., 2017). In the European Union, processed animal protein (PAP) as a feed ingredient is prohibited by the transmissible spongiform encephalopathy (TSE) Regulation 999/2001. Later, though, the ban was amended to permit the use of processed animal protein for aquaculture diets that came from sources other than ruminants. In light of this, the International Platform for Insect and Feed (IPIFF) has expressed a wish to alter the EU feed legislation to permit the incorporation of insect products raised entirely on vegetable substrates as a source of protein for pigs, poultry, and aquaculture (Lahteenmaki-Uutela et al., 2017). When compared to conventional protein sources, the production of insects is probably going to result in lower greenhouse gas emissions, water use, and land use. However, optimal rearing conditions and methods are yet to be determined (DiGiacomo & Leury).

**Aquaculture and fisheries by-products**

All the portions of farmed and captured fish, such as the head, fins, scales, skin, bones, and viscera, as well as shellfish crustaceans, such as the carapax, exoskeleton, shell, and debris, that are removed during processing for human consumption, are referred to as "fishery and aquaculture by-products." These byproducts can be utilised to make fishmeal and fish oil that are excellent for feeding animals. They are also a rich source of macro and micronutrients (Li, Liu, & Yan, 2019). Depending on the kind of fish and the portion of the fish under consideration, different fish by-products have different nutritional values. For instance, according to dry matter, the protein composition of the skin of...
metric tons (MMT). In contrast, animal proteins sourced from rendering facilities and capture fishing, such as fish meal and soluble, contribute a relatively minor share to the world’s overall protein meal output. The combined worldwide production of fish meal and soluble hovers at around 6–7 MMT, contingent on the output from major industrial fisheries in Peru and Chile (Barlow, 2002). To demonstrate the scale of fish meal derived from fish processing by-products, consider that Alaska’s annual fish harvest for human consumption exceeds 2 million metric tons (MMT). Nonetheless, the fish meal produced in Alaska represents just a small fraction, ranging from 1 to 2%, of the total global fish meal production (P. Bechtel, 2003).

Fish meal serves as an excellent component in aquaculture feeds due to its high-quality protein, which complements most plant-based proteins in feed formulations. Furthermore, fish meals typically boast significant quantities of long-chain omega-3 fatty acids and minerals, making them nutritionally valuable. They are also known for their appealing taste to aquatic species. The quality of fish meals has advanced thanks to various factors, such as a focus on using fresh raw materials and employing low-temperature drying techniques. Fish meals are frequently incorporated into the nutrition of young pigs, and feed components derived from hydrolysates have found applications in aquaculture, as well as in the diets of young pigs and calves. Young pigs weaned early necessitate specialized dietary elements until their digestive system matures completely. Some have proposed the use of more cost-effective, specialty fish meals as a substitute for the costly spray-dried animal plasma (Van Dijk, Everts, Nabuurs, Margry, & Beynen, 2001). Studies have also revealed that the inclusion of marine fish oils in diets for pregnant sows can improve fetal survival rates, art from their role as feed components for farm animals, fish by-products have been incorporated into pet foods to provide protein and oil, and there is a growing enthusiasm for utilizing products derived from fish by-products to improve the well-being of pets (P. Bechtel, 2007).

**Single-cell proteins (SCP)**

Single-cell protein (SCP), the first byproduct of fermentation, has shown to be a useful protein replacement. There is growing rivalry over food as the world’s population rises and soon, SCP might be able to compensate for deficiency of protein. Numerous multinational corporations are placing a high priority on SCP manufacturing, and as knowledge and time permit, the range of applications for this technology is growing. Microorganisms, such as algae, yeast, fungi, and bacteria, can create vast amounts of SCP due to their rapid growth rate and high protein concentration in their chemical composition. In addition to proteins, SCP also includes lipids, minerals, vitamins, nucleic acids, and a variety of important amino acids (Bratosin, Darjan, & Vodnár, 2021). The following types of single-cell proteins are discussed in detail.

**Figure 2 Steps employed during the production of single-cell proteins at the industrial level.**

**Microalgae**

Owing to their fast growth rate, ability to be cultivated in saline water, and lack of need for arable land or artificial fertilisation, marine microalgae hold great promise as a sustainable substitute for traditional terrestrial animal feed (Overland, Mydland, & Skrede, 2019). The nutritional content and chemical composition of microalgae vary depending on geographic origin, harvesting season, and associated environmental conditions (Jensen, 1993). Brown (Phaeophyta), green (Chlorophyta), and red (Rhodophyta) algae are the three different types of marine microalgae, which are multicellular protists that resemble plants. Fucoxanthin, a pigment, is responsible for the brown colour of Phaeophyta, phycoerythrin is responsible for the red colour of Rhodophyta, and a variety of pigments such as chlorophyll, a and b, carotenoids, and xanthophylls, are linked to the green colour of Chlorophyta (Kadam, Tiwari, & O’Donnell, 2013). The protein content in microalgae may be challenging to interpret due to the different methodologies used in various studies. Nevertheless, microalgae produce nitrogen which is a critical component of amino acids, proteins, and chlorophyll. On the other hand, brown microalgae generally have low protein content, usually below 150 g/kg of dry matter. Meanwhile, on a dry matter basis, green and red microalgae have higher protein content (Dawczynski, Schubert, & Jahreis, 2007; Lourenço, Barbarino, De-Paula, Pereira, & Marques, 2002). The proximate composition of marine microalgae is given in Table 4.

**Table 4 Proximate composition of marine microalgae**

<table>
<thead>
<tr>
<th>Chemical constituent</th>
<th>Brown microalgae</th>
<th>Green microalgae</th>
<th>Red microalgae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water, g kg⁻¹ of wet biomass</td>
<td>610–940</td>
<td>780–920</td>
<td>720–910</td>
</tr>
<tr>
<td>Crude protein</td>
<td>24–168</td>
<td>32–352</td>
<td>64–376</td>
</tr>
<tr>
<td>Crude lipids</td>
<td>3–96</td>
<td>3–28</td>
<td>2–129</td>
</tr>
<tr>
<td>Polysaccharides</td>
<td>380–610</td>
<td>150–650</td>
<td>360–660</td>
</tr>
</tbody>
</table>

Proximate composition of marine microalgae. All the values are presented in the g/kg. Table adapted from (Overland et al., 2019). Numerous microalgal species possess an amino acid composition wherein the ratio of essential amino acids (EAA) to total amino acids (TAA) surpasses 450 g EAA kg⁻¹ of TAA (Angell, Angell, de Nys, & Paul, 2016). When compared to fishmeal, microalgae generally have lower lysine concentration, but red algae may have higher lysine content than green and brown algae. Many microalgae species have low histidine contents, although many also have quite high methionine contents. Glutamic acid is commonly present in microalgae in high concentrations, both free and bound to proteins (Mazure, Malde, Eilertsen, & Eltovell, 2014).

**Bacterial proteins**

A variety of bacterial species have been investigated for protein production, therefore discussions on bacterial proteins are currently underway in addition to microalgae. As amino acids constitutes of lysine and arginine, the ratio of sulphur, bacteria produce a lot of high-quality protein. Hydrocarbons or their derivatives are used as substrates in the production of these proteins. To guarantee the calibre of the finished product, the production process must be closely regulated. Microbial protein products are currently offered on the feed market following several years of feeding trials in toxicology and nutrition conducted on a variety of domesticated animals.

**Yeast and Fungi**

Yeasts are a rich source of B complex vitamins and include modest levels of provitamin D and vitamin E. They are also a possible supply of protein due to their low sulphur content amino acids. Yeasts are more widely accepted as a source of protein by consumers, have a larger size, less potential for toxicity, and a lower nucleic acid content than bacteria. In a similar vein, mushrooms can be used as a source of protein. The idea of using fungal mycelium as a protein source for mass cultivation is relatively new. A variety of substrates, such as corn and wheat, can be utilised for fungal growth. The use of micro-algae as an animal feed is a relatively new concept. Algal biomass has the potential to be a useful feed supplement or replacement for conventional protein sources like soybean meal, fish meal, and rice bran, according to several nutritional and toxicological studies. Since poultry presents the most promising opportunity for commercial usage in animal nutrition, poultry is the main domestic animal target for adding algae to their diets. Aquaculture is also using microalgae more and more. Approximately thirty percent of the world’s algal production is currently sold for use in animal feed (Becker, 2007). Over time, scientists have found that raising algae in tap water and ponds can aid in the growth of fish raised for aquaculture. Furthermore, adding 6–10% algae produced in sewage to a barley-based diet helps sustain the growth rate and feed conversion efficiency of pigs in the growing–finishing stage of their lives (Hintz & Heitman, 1967). The apparent digestibility of the diets decreased when piglets were weaned early and their diet was substituted with S. maxima, which represented for as much as 12% of the total protein obtained from skim milk. Nonetheless, there was no discernible variation in the piglets’ growth when compared to the control group (Yap, 1982). The effects of supplementing sows’ diets with S. maxima were investigated. According to the data, the sows given algae gained less weight overall during their first reproductive cycle, but they produced more heavier piglets overall. The growth and litter characteristics of the algae-fed group and the control group did not significantly differ by the conclusion of the second reproductive cycle. Nonetheless, there was a greater rate of piglet culling in the sows fed algae. A further study was carried out to ascertain the effects of supplementing weaning pigs’ diets with a combination of S. maxima, A. platensis, or Chlorella sp. in place of 33% soybean meal. The findings showed that the pigs fed the regular diet and those fed an algae-supplemented diet did not vary in terms of body weight gain, feed efficiency, or incidence of diarrhoea. The pigs fed the algae-based diet showed symptoms of toxicity or digestive problems. De-fatted biomass from microalgal species can be a good alternative to maize and soybean meal in the diets of cattle, pigs and poultry, according to recent studies on the generation of biofuel (Lum, Kim, & Lei, 2013).
often lacks sulfur-containing amino acids, making it difficult for monogastric animals to digest their cell walls. Therefore, it is essential to determine the toxicoecological status of any microbial protein before using it as an energy source (Kuhad, Singh et al. 1997).

Although the discussed alternative sources of proteins have tremendous potential as a protein source for swine, and by recognizing the fact that protein shortage will be a global challenge in the coming years, better strategies need to be formulated to better utilize this alternative protein sources and any obstacles in the implementation of these protein sources, particularly their safety and acceptability need to be addressed through nutritional and health nutrition policymakers to achieve the desired goals towards overcoming protein shortage in the future.

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