Journal of Livestock Science and Production
p-ISSN 2598-2915
e-ISSN 2598-2907

BENEFITS OF GREEN SEAWEED AS PROTEIN SOURCE FOR BROILER: A REVIEW

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ABSTRAK

Produksi unggas memberikan kontribusi yang signifikan terhadap ekonomi pertanian. Nutrisi merupakan salah satu faktor penting dalam menghasilkan produksi ungags yang optimal. Saat ini, sudah banyak penelitian tentang alternative pakan alami atau feed additive dengan harga murah dan dapat membantu meningkatkan kinerja secara keseluruhan dan memperbaiki kondisi kesehatan unggas tanpa efek samping. Makroalga seperti rumput laut hijau dapat memenuhi parameter tersebut. Rumput laut mudah tersedia dan dianggap sebagai sumber yang kaya protein, polisakarida, karbohidrat, vitamin, mineral, pigmen, dan antioksidan. Seringkali, rumput laut digunakan sebagai aditif pakan unutk ayam broiler karena dapat memberikan dampak menguntungkan pada parameter produksi seperti bobot badan (BB), pertambahan harian rata-rata (PBBH), konsumsi pakan, dan rasion konversi pakan (FCR), serta kualitas daging. Namun, beberapa tantangan dalam pemanfaatan rumput laut hijau sebagai alternatif protein untuk ayam broiler seperti komponen toksik, dan antinutrisinya serta ketersediaan atau pasokan yang bervariasi karena pengaruh musim, penyakit, lokasi, dan pencemaran lingkungan. Tujuan utama kajian pustaka ini yaitu mengevaluasi berbagai penelitian yang dilakukan pada rumput laut hijau sebagai sumber protein potensial pada ayam pedaging.

Kata Kunci: *broiler, rumput laut hijau, protein alternatif, produksi unggas*

ABSTRACT

Poultry production contributed significantly to agricultural economy. Nutrition was one of important factor in having optimum of poultry production. Currently, there were a lot of research about natural alternatives or feed additives that are low in cost and can help increased the overall performance and improve poultry health conditions without any adverse effects. Macroalgae such as green seaweeds can meet these parameters. It was easily available and considered a rich source of proteins, polysaccharides, carbohydrates, vitamins, minerals, pigments, and antioxidants. Most often, seaweeds were used as feed additives for broiler chickens as they can induce a beneficial impact on production parameters such as body weight (BW), average daily gain (ADG), feed consumption (FC), and feed conversion ratio (FCR) and meat quality. However, there are several challenges in using green seaweed as a protein alternative for broiler chickens such as its toxic and antinutritional components, as well as varying available supply due to seasonal effects, diseases, location, and environmental pollution. Furthermore, the main objective of this review is evaluated to different research conducted on green seaweed as a potential protein source in broilers.

Keywords: broilers, green seaweed, protein alternative, poultry production

INTRODUCTION

In many countries, the poultry industry is a significant agricultural subsector. When compared to other domestic animals, poultry provide economic services to humans as a significant supplier of meat, egg, and raw materials for various industries (feather, waste products, etc.), as well as a source of revenue and employment (Ahaotu et al., 2019). According to the United States

Department of Agriculture (2020), the world's chicken meat production in 2020 increased more than in previous years. The demand for poultry meat to increase because, in the face of the economic crisis, consumers are looking for cheaper animal protein. Poultry is efficient in converting feed into high-value products within a comparably short period (El-Hack et al., 2016). Eggs and poultry meat are beginning to make a substantial contribution to relieving protein insufficiency in many countries (Alagawany & Mahrose, 2014). In today's poultry industry, practices regarding management and feeding composition are among the most important factors.

Currently, seaweed is starting to be widely used in order to control the high use of antibiotics in poultry feed which greatly impacts the increase in microbes. Resistance to antibiotics, and the presence of growth promoter antibiotic residues in animal products can cause serious health problems for consumers (Castanon, 2017). Therefore, alternative natural antibiotics are needed to increase poultry production through the use of seaweed. Seaweed known as sea algae has been used as animal feed in coastal areas since time immemorial. It is now emerging as an important and major livelihood in coastal areas, particularly in the Southern Philippines (BFAR, 2009). Seaweed is an easily available and renewable biomass that is rich in active compounds. Seaweed contains carbohydrates, proteins, minerals, vitamins, dietary fiber, a relatively balanced amino acid profile, and bioactive compounds (Piconi, 2020).

The gastrointestinal (GI) tract has the most extensive surface in the body and is the part that is often exposed to a variety of potentially harmful substances (Yegani and Korver, 2019). The Gut microbiota plays an important role in animal health and productivity in commercial broiler chickens (Carrasco et al., 2019). In the post-hatching period, the small intestine continues to gain weight more rapidly than any other body mass due to enzyme activity and absorption (Geyra et al., 2001). The digestive process is strongly linked to gut microbiota; nutrient absorption, feed digestibility, energy harvest, and therefore productivity are influenced by microbiota composition and diversity (Mancabelli et al, 2016). In this review, most of the information is available about the different research conducted on green seaweed as a potential protein source in broilers.

RESULT AND DISCUSSION

Green seaweed as a protein source

Species of edible green seaweed

Green seaweeds (Chlorophyta), of which there are 2,200 known species, can grow up to 1 meter in height (Makkar et al., 2016). Its characteristic color is associated with the presence of chlorophyll a and b pigments, which are used in the photosynthetic process. Their coloration is determined by the ratio of chlorophylls and other pigments, such as β-carotene and xanthophylls. Green algae thrive in areas with abundant light, such as shallow water and natural pools. *Ulva*, *Codium*, *Chaetomorpha*, and *Cladophora* are the most significant genus (Corino et al., 2019).

Ulva sp. is commonly known as one of the most common genera of edible green seaweeds that are being studied. They are fast-growing algae that can reach a length of 45 centimeters and can be found worldwide in the intertidal zone of brackish or marine environments, particularly in estuaries (Edwards et al., 2012). These species are high in minerals, proteins, and vitamins; thus, it is frequently associated with research studies (Jamal et al., 2017). However, *Ulva* spp. can cause algal blooms called "green tides" which are a major environmental issue in several countries and contribute to the ecological imbalance in coastal ecosystems. Green tides are associated most often with areas that have optimal environmental conditions (temperature and high concentration of nutrients) suitable to them (Yabe et al., 2008). Moreover, regardless of scale and geographic location, it occurs as vast accumulations of monospecific green macroalgal biomass that multiply uncontrollably and become dominant and overwhelming with biomass accumulation (Blomster et al., 2002).

Production of seaweed meal

Seaweeds can grow in different environments and each species has different requirements of water, salinity, nutrients, water movement, temperature, and light. In species that reproduce asexually, bits of seaweed are attached to ropes or nets, also being held in place by a fork-shaped tool (in sediments) or sand-filled tubes (in sandy soil) at the bottom of the pond. This species could be harvested by removing the whole plant or most of it but only small pieces that are used as seed stock for future cultivation. In some sexually producing seaweeds, only the large sporophyte form is harvested for production (McHugh, 2003).

Seaweeds must be processed immediately after collection for seaweed meal production because they are high in water content and can be moldy easily. Seaweeds are then washed with fresh water, dried, and milled before being used as a feed additive. Washing of seaweeds with freshwater reduces ash contents (Zeweil et al., 2019). The ash contents include external and internal salts which usually account for 20 to 50% of the dry weight (Angell et al., 2015). The high salt content in feed can cause diarrhea and death of poultry (Dewi et al., 2018). Accordingly, washing with freshwater can potentially increase the concentration of protein in seaweeds by an equivalent amount. Although, seaweeds with a high concentration of essential amino acids such as polysaccharides, which could account for up to 76% of the dry weight (Kraan, 2012), are not affected by washing. In the study by Neveux et al. (2014), the concentration of protein in the siphonous green seaweed *Derbesia tenuissima* and the green blade seaweed *Ulva ohnoi* increased by 34% and 15% respectively after washing. Similarly, Dewi et al. (2018), showed that after 15 hours of immersion of *Sargossum binderi* in a flowing river, it enabled a decrease in the salt and ash content and an increase in the organic matter and crude protein content in the algal biomass.

Subsequently, it is dried using either a drum-dryer or air drying. The drum-dryer begins the process at a temperature of 700-800 °C and ends at no more than 70 °C. Sun-drying on the other hand is not advisable in preparing a valuable feed additive as it causes degradation of vitamin C as well as carotenoids in seaweeds, which are known to enhance the color of animal products (Carrillo et al., 2008). Thus, it is recommended that seaweeds be air-dried in shaded areas (Bai et al., 2019). The seaweeds are then passed through hammer mills with progressively smaller screens to reduce them to fine particles. Seaweed meal must be placed in sealed bags with a final moisture level of about 15%. Storage of seaweed meal can last for about a year if it is properly stored because seaweeds contain several phytochemicals. Drying and storage at room temperature would allow the least inactivation of the bioactive compounds (McHugh, 2003).

Nutritional value and chemical composition of seaweed

Nutritional value

The distinct nutritional composition of seaweed is highly important in poultry nutrition. Its composition varies, depending on the type of species, location, season, and environmental parameters. Seaweeds contain a high concentration of minerals, polysaccharides, vitamins, natural pigments, dietary fibers, proteins, and lipids (Burtin et al., 2002). Seaweeds are an excellent source of minerals such as Ca, Mg, Fe, Cu, I, Mn, and Se, as well as P and Zn to a lesser extent (Cabrita et al., 2016). These mineral contents must be considered during feed optimization because their availability is greater than that of inorganic compounds (Evans and Critchley, 2013). It was also confirmed in the study of Michalak et al. (2011), where the bioavailability of minerals bound with green seaweeds was better than inorganic salts of these microelements. Additionally, seaweeds are high in both structural and storage polysaccharides. Their structural polysaccharides are similar to terrestrial plants which are mainly celluloses, hemicelluloses, and xylans. However, the storage polysaccharides are usually specific to species and are the most commercially consumed components in it (MacArtain et al., 2007). For the dietary fiber composition of seaweeds, it may be used as an alternative for improving intestinal integrity and lowering serum lipid concentrations (Canedo-Castro et al., 2019).

Seaweeds are also composed of different vitamins such as vitamins A, B, C, D, and E, riboflavin, niacin, pantothanic acid, and folic acid. It does have more than 54 trace elements, which are required for physiological functions, in far greater quantities than terrestrial plants (Chapman and Chapman, 2000). Thus, seaweeds are recommended as feed additives because of their high content of micro and macro elements, which can help to prevent elemental deficiencies, enrich eggs with minerals, improve the meat quality, and aid in bone mineralization (El–Deek and Al– Harthi, 2009). The pigments contained in seaweeds are also known to be important in poultry nutrition and production because of its antioxidant potential and usefulness for pigmenting food products (Herber-McNeill and van Elswyk, 2008). For instance, the pigment carotenoid from seaweeds is distinctive, as they have all types of pigments, as expected from terrestrial resources (Rodríguez-Bernaldo de Quiros et al., 2010). The protein content of seaweeds ranges from 5 to 35% of their dry weight. These levels are comparable to those found in high-protein crops like soybeans and wheat.

The proportions of essential amino acids are almost similar to traditional soybean and wheat. Seaweeds are generally richer than soybean meal but lower than wheat flour. However, it contains less lysine than soybean meal and wheat flour (Maehre et al., 2014). Furthermore, lipids make up about 1–5% of algal dry matter (Burtin et al., 2002; MacArtain et al., 2007) which can be a good source of polyunsaturated fatty acids, so they can be used as an alternative to flaxseed, fish oil, fish meal, and canola to increases the n-3 fatty acid content of eggs and chicken meat (González-Esquerra and Leeson 2001).

Phytochemical properties

Seaweeds are constantly exposed to a variety of abiotic stresses, including desiccation, sunlight, osmotic stress, extreme temperatures, as well as pathogenic microbes. Seaweeds have developed protective mechanisms in response to these stressful conditions to combat and survive them (Sampath-Wiley et al., 2008). They produce a diverse range of bioactive compounds, such as sulfated polysaccharides, organic acids, pigments, and phenolic compounds, which are responsible for a variety of functions such as antioxidant, anti-microbial, and anti-viral activity.

The main groups of antioxidants in seaweeds are polyphenols, polysaccharides, and pigments (Izabela et al., 2022). Phlorotannins, seaweed polyphenols, may have a wide range of potential biological activity unlike terrestrial plant polyphenols (Burtin, 2003). Another polyphenol that can be found in seaweeds is flavonoids, which show the antioxidant property of green seaweed through a potential free-radical-scavenging activity. (Chakraborty and Paulraj, 2010).

Furthermore, the presence of bioactive compounds such as carrageenan, ulvan, alginate, fucan, and laminaran contribute significantly to the antiviral property of seaweeds (Ahmadi et al.,2015). Elizondo–Gonzalez et al. (2012), demonstrated the action of ulvans against the Newcastle disease virus. It works by preventing viral-induced syncytia creation by potentially blocking the F protein, which is responsible for cell membrane and viral envelope fusion through conformational modifications. Moreover, fucoidan, a seaweed polysaccharide, can also improve the host anti-viral immune response to stimulate both specific and non-specific responses such as the activation of NK cells, maturation of dendritic cells, and activity of cytotoxic lymphocytes, as well as the ability to produce antigen-specific antibodies and memory T cells under in vitro and in vivo conditions (Zhang et al., 2015)

Seaweeds can also act as prebiotics or “a non-digestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria, already established in the colon and thus improves host health” (Gibson et al.,2005). According to Kulshreshtha et al. (2014), seaweed polysaccharides can improve poultry performance, egg quality, and overall gut health because of their prebiotic activity. Similarly, in the study of Canedo-Castro et al. (2019), *Ulva* sp. supplementation in a broiler diet can increase the growth of intestinal villi and decrease serum total cholesterol and triglyceride concentrations. So that seaweed can be used as a prebiotic to improve broiler health. The dry weight of *Ulva* sp. biomass is composed of 9 to 36% of ulvan, a heteropolysaccharide of the cell wall (Hamed et al., 2015). Ulvan can help in the regulation of immune functions and act as an antioxidant and antibiotic due to its composition such as rhamnose, xylose, glucose, uranic acid, and sulfate (Usov, 2011). In the study Pereira (2018) reveals that a high level of sulfated polysaccharide in *Ulva* sp. can demonstrate its anticoagulant, antiviral, anti-inflammatory, antihyperlipidemic, immunomodulatory, and anticancer activities.

Antibacterial and antiviral effects

Seaweeds in poultry diets enhance gut microbiota, as the algal biomass remains mostly undigested in the lower GIT, and therefore acts as substrates for bacterial fermentation. Seaweeds have prebiotic-like properties that alter the metabolic activities of beneficial microflora and reduce the prevalence of pathogenic bacteria (Kulshreshtha et al., 2020).

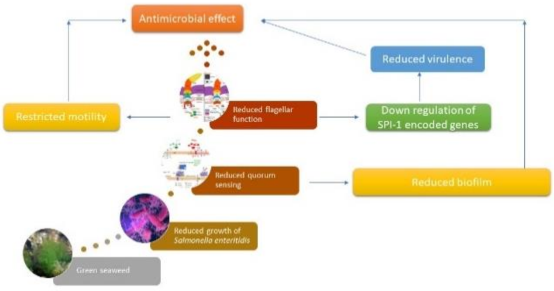

Figure 1. antimicrobial effect of green seaweed

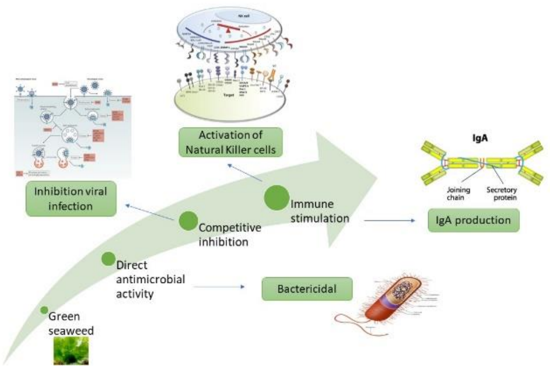

Figure 2. mechanisms of antibacterial and antiviral by seaweed

Seaweeds and their bioactive compounds, such as polysaccharides and phenolics, exhibit these characteristics and can be considered prebiotic dietary supplements with gut health benefits. In poultry, prebiotics has been shown to improve gastrointestinal health by providing a substrate for beneficial bacteria within the gut microbiota of chickens (Matshogo et al., 2021). The mode of action of most prebiotics is by one or more of the following mechanisms: lactic acid production, inhibiting/preventing colonization of pathogens, modifying metabolic activity of normal intestinal flora, and stimulation of the immune system (Corino et al., 2019). Sulfated polysaccharides (laminarin and fucoidan) act as antioxidants due to their hydrogen, which combines with radicals and makes it a stable radical to cut off the radical chain reaction (Michalak et al., 2022). The positive effect on animal health was modulating the gut environment, stimulating the innate immune system, reducing the risk of diarrhea, enhancing growth performance, and promoting productivity (Del Tuffo et al., 2019). Furthermore, sterols have shown anti-inflammatory and cholesterol-lowering activities (Hayes, 2019). However, seaweed has low digestible protein in terms of being an appropriate substitute protein source in livestock feed (Overland et al., 2019).

Effects of green seaweed in broiler

Production parameters

Broiler's feed is primarily composed of corn and soybean meals, whereas corn is used as a source of energy in most parts of the world due to its abundance and digestibility. As time goes on, high corn prices led to new research on feed additives that is as capable as corn in providing the required nutrients and attaining the growth parameters in broilers. Live body weight (BW), average daily gain (ADG), feed consumption (FC), and feed conversion ratio (FCR) are all factors that should be considered in poultry growth performance (Michalak and Mahrose, 2020). *Ulva* sp., a common green seaweed, has been extensively studied as a feed additive in broiler chicken diets due to the soluble fibers and essential sulfur-containing amino acids. Matshogo et al. (2020), discovered that the inclusion of green seaweed in broiler chicken diets could compromise the performance and feed efficiency. This was attributed to the seaweed's high levels of indigestible non-starch polysaccharides like cellulose, hemicellulose, xylans, and ulvans (Gullon et al., 2020). Similarly, the same result was observed in the study of El-Deek et al. (1987) and Abudabos et al. (2013). The effect of supplementation of green seaweed is shown in table 1.

Table 1. Performance production of broiler supplemented by green seaweed

Supplementation	Result	References
4% of seaweed	increased body weight gain	Abudabos et al., (2013) Asar (1972),
3% *Ulva* sp	improved body weight gain, fats, and protein contents	Zahid Phool et al. (1995),
10% of *Ulva* sp	increased body weight gain	Ventura et al. (1994)
Seaweed with *Azolla*	increase in body weight	Thavasi-Alagan, et al., (2020)
seaweed meal	no effect on the overall body weight gain	Matshogo et al. (2020)
seaweed meal	Increase 32% gain on day 1-21 broiler chickens, and a 68% gain during the finisher period (days 22-42)	Canedo-Castro et al. (2019),
3% of *Ulva* sp	no effect on average daily gain of day 12 to 33 broiler chickens	Adubados et al. (2013)
15% seaweed	growth rate slowed	Carrillo et al. (2008)
4% and 6% seaweed	Increase feed conversion	Michalak and Mahrose (2020), Cruz-Suarez et al. (2000) (Stokvis et al., 2021)
Ulva sp	no significant feed conversion	Abudabos et al. (2013)
Up to 30.0% of *Ulva* sp	Decrease feed conversion	Ventura et al. (1994)

Furthermore, it was found in the study by Wang et al. (2013) and Sun et al. (2010), that broilers fed with 2 to 4% of green seaweed, given with best nutrient availability and high apparent metabolizable energy, may be associated with the high level of amylase in the duodenum. It does have a beneficial impact on FC, FCR, and ADG while reducing abdominal and subcutaneous fat thickness, thus improving breast meat quality. Whereas Jamal et al. (2017), stated that the use of *Ulva* sp. in animal feed is challenging because the polysaccharide bioavailability is still indescribable due to the inefficient animal metabolism of this nutrient. Gullon et al. (2020), stated that the presence of non-starch polysaccharides in seaweeds, such as cellulose and hemicellulose, may limit their use as a feed additive. It was demonstrated that high levels of cellulose and hemicellulose reduce digestibility in chickens by interfering with the bioavailability of beneficial bioactive compounds, and as a result, growth performance and meat quality, and stability are all reduced. Hence, this limitation hinders *Ulva* sp. from being used effectively as a sole feed for animals.

Meat quality

In the broiler industry, meat quality is a major concern because nowadays consumers demand healthy and nutritious products. Meat and meat products' quality is usually characterized by color, shelf-life, tenderness, water holding capacity, and nutrient profile (Muchenje et al., 2009). Managing effectively these parameters is most important since all of them can influence one another. Seaweeds can be part of an efficient poultry product that produces health benefits for consumers and natural preservatives that extend shelf life as it contains a broad spectrum of bioactive compounds (Sweeney and O'Doherty, 2016).

In the study of Ali and Memon (2014), broilers showed meat quality when less than 3% green seaweed was added to the animal diet. It was concluded that a high amount of crude protein and amino acids (especially methionine) are essential in the improvement of dressing and breast yield. A similar study was conducted by Abudabos et al. (2013), after supplementation of 3% green seaweed to broiler chickens increased dressing and breast yield while reducing the abdominal fat percentage was seen. Cafe and Waldroup (2006) reported that feeding of *Ulva* sp. resulted in a notable reduction of abdominal fat. Derived from the analysis, the percentage of *Ulva* sp. was increased as the level of the crude protein. The same findings were obtained by Moran et al. (2002) who demonstrated the significant influence of crude protein level on abdominal fat deposition, as the crude protein intake increased, abdominal fat deposition decreased. In a similar manner, Lahaye (2001) and Lahaye and Jegou (2003) stated the presence of 21.3% soluble fiber in *Ulva* spp. might be responsible for lowering abdominal fat.

Seaweeds can prevent microbial growth and delay oxidation reactions in meat products because of their antimicrobial properties (Roohinejad et al., 2017). Indeed, in the study of Kumar et al. (2015), animal diets with seaweed compounds have been reported to increase shelf life during processing and storage. Repeated analysis revealed the effects of diet and time interaction on shelf-life indicators such as the pH, lightness, and redness of meat, data shows that dietary effects on indicators were time-dependent. It was demonstrated that the lightness and redness of meat products at room temperature can be affected by the dietary seaweed meal but not meat yellowness. For the pH values, Matshogo et al. (2020) showed that after three days of storage at room temperature, meat with green seaweed supplementation failed to maintain a normal pH level. According to Dyubele et al. (2010) and Muchenje et al. (2009), meat pH level is affected by the amount of glycogen in meat muscle prior to slaughter and the rate at which the remaining glycogen after slaughter is converted to lactic acid. Hence, the lack of dietary effects on pH could indicate that seaweed meals did not interfere with the glycogen levels. Contrary results were presented by Canedo–Castro et al. (2019), who found no significant differences in the overall meat quality yield of broilers fed with various concentrations (2%, 4%, and 6%) of *Ulva* sp. inclusion in the diet. Barbut (2007) and Matshogo et al. (2020), demonstrated that the inclusion of seaweed in the diet had no effect on the meat quality parameters of the birds.

Application of seaweed in the Philippines

Production capacity of green seaweed

The Philippine archipelago consists of over 7,000 islands directed from north to south and is bounded by different seas and oceans. Its geographical location is within the Coral Triangle characterized by warm, clean, and clear water and tolerable weather which has been confirmed to be advantageous for commercial algal farming (Hurtado et al., 2015). In addition, the Philippines' flora is among the most diverse in the Asia-Pacific region. According to Fisheries Policy and Economics Division, BFAR (2010), more than 800 species of seaweeds have been recorded in the country.

Following China and Indonesia, the Philippines is the third largest seaweed producer in the world (FAO, 2018). Hence, seaweed farming has been a significant source of income for Filipinos, particularly those living in the coastal regions of the Visayas and Mindanao. In 2008, seaweeds contributed about 34% of the total aquaculture production, with Regions IV-B, IX, and ARMM as major producers. In the data presented by Philippine Fisheries Profile, in 2011 the country produced its highest production volume of 1,840,832 metric tons of seaweeds. These constant increases in production can be attributed to the rising market demand, better prices, and favorable weather conditions, which encourage farmers to expand their seaweed cultivation areas.

Over 60,000 hectares of reef and shallow coastal areas are being used for seaweed farming which is currently one of the most productive aquaculture activities undertaken in the Philippines. This corresponds to the productivity of ~20 tons of fresh weight hectare per year (Trono and Largo, 2019). *Ulva* and *Caulerpa* species are some of the many seaweed species that the Philippine government is encouraged to be developed as a potential human and animal food, as well as a biogas feedstock. The FAO database has long listed these two species as the most important macroalgae for commercial use in various parts of the world (Naylor, 2006). Both green seaweeds are gaining interest due to their enriched nutrients and various health-promoting compounds. Thus, the farming of *Caulerpa* and *Ulva* is expanding worldwide (de Gaillande et al., 2017) to meet this growing demand from the market.

Socio-economic importance of seaweeds

Seaweed farming could really be a great opportunity to be an alternative source of income for Filipinos. The industry can help generate income for more than 500,000 manpower where almost 90% are seaweed farmers and the rest are seaweed processors and traders. In addition, at least 10,000 job opportunities have been created through other related activities. (Fisheries Policy and Economics Division, BFAR, 2010).

The industry has been interesting for the communities in coastal areas due to its simple process of farming that doesn’t need much technology, requires low production costs, and the crop can be rapidly harvested after 6 weeks. Similar reasons were concluded by Salayao et al., (2001), as stated in their study that the commercial seaweed production in the Philippines is advantageous as compare to other developed, temperate countries and even in some tropical countries. Moreover, since the farming areas are in intertidal zones, women and children can easily be involved in farming. Hence, it could be a great opportunity for them to generate extra income for themselves and for their families while the men work in other fields. This trend is seen in regions of Asia and the Pacific and Africa (FAO, 2018).

The Philippines' seaweed industry is highly export-oriented. In 2016, the Philippine Statistics Authority reported that seaweed exports tallied nearly 43,000 tons, with a custom declared value of USD 200 million.

Challenges in substitution with green seaweed

Toxic and antinutritional components of seaweeds

Seaweed biomass is an important alternative feed additive for livestock. However, its utilization as feed additives may be limited due to the availability of toxic metal components such as cadmium, lead, mercury, tin, and arsenic (Holdt and Kraan, 2011) and of antinutritional components. These parameters differ in every species. Environmental conta-minants such as heavy metals can alter the chemical composition of micro-and macroalgae, with effects on pigment composition (Pinto et al., 2003) and photosynthesis (Connan and Stengel, 2011a). Le Faucheur et al. (2006) found that changes in glutathione and phyto-chelatin concentrations were observed under copper contamination in green seaweed. The phytochelatins that were induced by high metal contamination in macroalgae have been confirmed. Although phytochelatins are induced by many algal taxa in response to high metals, this is not a classic reaction and was not observed for all species examined (Pawlik- Skowrońska et al., 2007). Hence, seaweed when used in animal feeds is tested to evaluate the levels of metals. On the other hand, many algal metabolic pathways, including photosynthesis (Burkhead et al., 2009), require the presence of metals. However, algae can also bioaccumulate phenolics, polysa-ccharides, and proteins which have a high affinity for some metals (Cherry et al., 2019) hence, limiting their commercial applications.

Most potential alternative plant-derived nutrient sources are known to contain a wide range of antinutritional substances. Antinutrients are substances that, either directly or through metabolic products produced in living systems, interfere with food utilization, and pose a negative impact on animal health and production (Makkar, 2003). In the study of Francis et al. (2001), the presence of antinutrients, particularly lectins, in seaweeds can interfere with digestion and feed utilization processes. Furthermore, seaweeds contain tannins, trypsin, alpha-amylase inhibitors, and phytic acid which are also considered antinutritional factors because they might interfere with the bioavailability and/or digestibility of some nutrients, such as proteins and trace minerals (Rehman and Shah, 2004).

Varying supply of seaweed

Even with continuous increases in seaweed production and economic growth, problems and constraints are still existing in the seaweed industry. One problem is the varying supply of seaweeds as it is affected by several factors such as seasonal variations, diseases, geogra-phical location, and environmental pollution.

According to Rajauria (2015), seasonal variation is the major problem associated with seaweeds' nutritional properties. It was discovered in the study of Francavilla et al. (2013), that protein concentration varied significantly throughout the year, with higher concentrations in the winter and lower concentrations in the summer, with statistically significant differences between months. Nutrient availability is affected by both biotic and abiotic factors, with the latter including temperature, light, desiccation, carbon availability, salinity, and water motion (Roleda and Hurd, 2019). According to Ordun a-Rojas et al. (2002), metabolic responses (photosynthesis and growth rates) and levels of proximate constituents in seaweeds can be altered if exposed to seasonal variations in abiotic factors.

Diseases in seaweeds are another factor that could affect the varying supply of seaweeds. It tends to affect the structure and function of seaweeds and alters growth rate and appearance, which may result in poor product quality (Andrews, 2006). The ice-ice disease is one of the major problems in the cultivation of seaweeds. It is a non-infectious disease triggered by unfavorable environmental conditions such as high temperature, pH, and salinity, as well as opportunistic bacterial pathogens. It causes pigmentation loss, thallus softening, and detachment of affected plants from seaweed cultivation lines (Arasamuthu and Edward, 2018). Accordingly, seaweed production is significantly decreased. In the Philippines, ice-ice disease occurrence caused a drastic decrease in production between 2011 and 2013 (Cottier-Cook et al., 2016).

CONCLUSION

Seaweeds have been utilized in broiler feed as a rich source of protein, carbohydrates, vitamins, minerals, and dietary fibers with relatively well-balanced amino acid profiles and a unique blend of bioactive compounds. Seaweed can be an alternative feed additive for livestock by decreasing the levels of heavy metals as the limiting commercial applications.

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