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The marine environment is an untapped source of bioactive compounds and seaweeds represent a valuable tool to improve the quality of bee feed.


A bee pollinating lemon flowers.
Photo by Jon Sullivan

Honeybees are of huge economic importance, they are responsible for pollinating agricultural crops that make up one-third of the food we eat, including fruits and vegetables. “Honeybees are the cornerstones of heart-healthy and cancer prevention diets" says Gloria DeGrandi-Hoffman, an adjunct professor in the Department of Entomology in the College of Agriculture and Life Sciences at the University of Arizona and a research leader at the Carl Hayden Bee Research Center in the Agricultural Research Service of the U.S. Department of Agriculture.

Unfortunately, however, for the past two decades beekeepers have had a hard time: heavy colony losses have been repeatedly reported worldwide and honey bee health has become an issue of growing concern.

The phenomenon of colony losses can be driven by different factors, as explained in an article by Maini and co-workers, which describe this phenomenon as a puzzle[1]. The synergistic effect of pesticides, infectious diseases, climate changes, poor nutritional sources and beekeeping practices may result in a substantial effect. Among these factors, honey bee diseases and parasites play a crucial role in affecting general honeybee health.

Nowadays, it is widely known that there is a very strong correlation between nutrition and health status of animals and diseases occurrence. Adequate nutrition supports the development of healthy and, consequently, more productive animals.
Deficient, excessive, or unbalanced nutrient intake, especially those that cannot be sufficiently synthesized by the body, affects the ability of animals to convert food into energy, which is necessary for the correct growth and vital biological functions. Moreover, all nutrients are considered crucial factors in controlling the immune system and an efficient immune system is necessary in the fight against infectious diseases and parasites.[2]

And bees do not escape the necessity for adequate nutrition!

A solution for animal (and bee) nutrition may come from the sea!

Uses of seaweeds

Sushi, a traditional japanese food using seaweed

Nowadays seaweeds have many uses. They are consumed as food especially in Asia; in Japan, for example, the red seaweed Nori (*Pyropia* and *Porphyra*) is a traditional wrapping for sushi and is eaten in soups, Wakame (*Undaria pinnatifida*) and kombu (*Saccharina japonica*) are cultivated for food.

As a wholefood it is not considered a habitual component of the diet in the West countries, where seaweed components are rather used in industries.
Seaweeds in fact, provide numerous ingredients to food, cosmeceutical and pharmaceutical industries, such as hydrocolloids (used as stabilizers, thickeners and fillers), pigments, vitamins, chelated micro-minerals, prebiotic substances and phlorotannins.

Agar-agar is a common jellying agent used in different food production and is derived from seaweeds

Seaweeds are used in medicine for the treatment of iodine deficiency (goiter, Basedow's disease and hyperthyroidism), for intestinal disorders, as vermifuges (therapeutic agents used to treat infections with parasitic worms), and as hypocholesterolemic and hypoglycemic agents[3].

Seaweed are also used as organic fertilizers that are usually rich in potassium but poor in nitrogen and phosphorus, and some seaweed species, such as *Gracilaria* (red algae) and *Ulva* (green algae), are suitable for bioremediation, a process that uses living organisms, mostly microorganisms and plants, to degrade and reduce or detoxify waste products and pollutants.

Seaweeds and nutrition

The use of seaweeds for both human and animal nutrition has a long history in coastal communities.

Sheep eating seaweed, Hamnavoe, Scotland. Photo by Matt Smith

In *Bellum Africanum*, written in 45 BC, the unknown author records that "in times of scarcity, they [the Greeks] collected seaweed from the shore and, having washed it in fresh water, gave it to their cattle and thus prolonged their lives"[4]. In Iceland, with extended period of harsh climate, seafaring traditions, and scarce supplies of animal fodder, seaweeds actually do have a long history of use. According to the Icelandic sagas, *Palmaria palmata* (local name "sol") was used as both human food and animal supply since at least the year 961. Sol was collected at low tide, washed in fresh water, dried like hay, and packed in barrels or huts where it was kept dry and compressed. For animal use, seaweeds were air-dried and stored in barns, in layers with each layer separated with a layer of hay. This stored seaweed was used as both human and animal food, when other sources were scarce[5]. There are also reports of seaweeds being preserved as silage and used as winter feedstuff for sheep and cattle in the early 1900s.[6, 7]

Cow eating kelp. Photo by Sean Davey

Seaweeds have seen a renewed interest as feed ingredients since the 1960s, when Norway started producing seaweed meal from kelp[8] and it is only recently that science has clearly understood how the unique properties within algae can be used to increase animal production and health.

Seaweeds are increasingly proving to be really beneficial nutritive tools. Even when used in small amounts in nutrition of different animals, seaweeds have been shown to improve the immune system and growth, with consequent improving of health and increasing of weight and productivity, resulting for example in the yield and quality of eggs and meat.[9, 10]

What are seaweeds?

The term "seaweed" does not have any taxonomic value, but is rather a popular term used to describe the common large marine algae and refers to several species of plant-like organisms that generally live attached to rock or other hard substrata in coastal areas. They have a highly variable composition, depending on the species, time of collection and habitat, and on external conditions such as water temperature, light intensity and nutrient concentration in water.

Ulva lactuca, also known as sea lettuce, an example of green alga.

Macrocystis pyrifera, also known as giant kelp, an example of brown alga used in animal feed.
Photo by Claire Fackler, CINMS, NOAA.

Gracilaria sp., an example of edible red alga. Photo by Eric Moody

Seaweeds include three main different groups, empirically distinguished since the mid-nineteenth century on the basis of thallus colour: brown algae (phylum Ochrophyta), red algae (phylum Rhodophyta), and green algae (phylum Chlorophyta). According to data stored in AlgaeBase, a database of information in algae, there are about 10,000 different species of seaweeds, of which 6,500 are red algae, 2,000 are browns and 1,500 are greens. Red and brown algae are almost exclusively marine, whilst green algae are also common in freshwater (rivers and lakes), and even in terrestrial (rocks, walls, houses, and tree bark in damp places) situations.

Properties of seaweeds

Seaweeds are able to absorb, through their fronds, nutrients from the area in which they are growing, terrestrial plants do this through their roots. But, while terrestrial plants depend only on the limited resources available in the specific area of soil in which they are growing, sea plants can absorb a rich variety of minerals and phytonutrients from the circulating seawater that are missing from soils. Ocean water is literally the lifeblood of the planet, providing a constant “reservoir” of all essential nutrients. Seaweed can store the nutrients they absorb in a colloidal structure, and, therefore, can be considered a really rich and powerful source of nutrients, including over 60 mineral elements. It has been estimated that algae contain 10 to 20 times the minerals of land plants. The mineral composition varies according to phylum as well as various other factors such as seasonal, environmental, geographical and physiological variations. An important mineral of which seaweeds are rich in is iodine, an essential nutrient required in very small amounts by

animals. It is a constituent of thyroid hormones thyroxine (T4) and triiodothyronine (T3), which play a major role in cell differentiation, growth and development in growing animals and in the regulation of metabolic rates in adult animals[11].

Moreover, seaweeds harbour a variety of components with different biological activities.
Marine algae have a high fibre content consisting of polysaccharides (complex carbohydrates made of many simple sugars). Polysaccharides like agar, alginates and carrageenan are economically the most important products from algae, widely used in the food industry as gelling or thickening agents in marmalade, ice-creams, jellies, etc. Certain algal polysaccharides are also of pharmacological importance, acting on the stimulation of the human immune system[12], or possessing different activity, such as antiviral[13, 14], anti-tumor[15, 16], or anticoagulant[17]activity.

The amount of protein in seaweeds varies with the species and the higher levels recorded can be comparable to those found in high-protein vegetables, such as soybeans, lentils, peas etc. Most seaweeds contain all the essential amino acids, including the eight essential amino acids (cysteine, isoleucine, leucine, lysine, methionine, phenylalanine, tyrosine and valine) that cannot be synthesised by animals, nor can they be replaced by other "less valuable" building blocks.

Further important components of seaweeds are lipids, a broad range of naturally occurring molecules, which include fatty acids, pigments, sterols and fat-soluble vitamins (such as vitamins A, D, E and K).
The most important algal fatty acids are the *n-3* Polyunsaturated Fatty Acids (*n*-3 PUFAs), commonly known as *omega-3,* essential fatty acids that cannot be synthesized by mammalian system. Omega-3 fats promote the production of anti-inflammatory chemical mediators and inflammation is the basis of chronic imbalances; therefore an adequate intake of omega-3 is beneficial both as prevention than as treatment of different diseases[18, 19]. Seaweeds are therefore an important source of supply of omega-3 for the maintenance of health.
Among pigments, of particular relevance are carotenoids. Carotenoids are known for their antioxidant properties, which have shown a role in preventing pathologies linked to oxidative stress[20, 21]. Fucoxanthin is one of the most abundant carotenoids in nature. Fucoxanthin isolated from seaweed has demonstrated anticancer effects on proliferation of human prostate cancer cells[22] and on leukaemia cell lines[23]. Moreover, algal fucoxanthin has been shown to be an effective natural food ingredient to prevent obesity[24].
Tocopherol, also known as Vitamin E, is another strong antioxidant and part of the carotenoid family. Vitamin E has a broad physiological importance, such as maintaining tissue's structural integrity, supporting neural growth, reproduction and modulating immunity.

Seaweed-based feed and animal health

Seaweeds cannot be considered as a main source of energy but they have nutritional value regarding vitamin, protein and mineral contents, which can be deficient from soils. They can replace the inorganic mineral salts that are most commonly used in the animal feed industry. According to Chapman, 100g seaweeds provide more than the daily requirement of Vit. A, B_1 and B_{12} and two thirds of Vit. C[25]. They are also natural sources of hydrosoluble and liposoluble vitamins, such as thiamine and riboflavin, b-carotene and tocopherols, as well as of long-chain polyunsaturated essential fatty acids from the omega-3 family such as eicosapentaenoic acid.

More and more consumers are focusing on sustainable, "chemical free" and organic farming and prefer to use the natural forms of vitamins and minerals instead of the synthetically produced ones. It has been suggested that the natural forms are more bio-available to the animal than the synthetic forms and can be even altered or manipulated via the process of bio-absorption[26].

The properties of seaweed components may benefit animals by improving their health in different ways:

- ✓ Provide mineral, trace elements and vitamins necessary for all biochemical reactions involved in the growth and vital biological functions of animals
- ✓ Enhance the immune system
- ✓ Improve metabolic processes
- ✓ Support the cardiovascular system
- ✓ Promote fertility

Thus, seaweeds are incredibly valuable to animal health, and are increasingly becoming an unrivalled multi-supplement food.

Seaweeds as prebiotics

An important application of seaweed for both human and animal health is their use as prebiotics.

The gastrointestinal tract of both humans and animals is a complex, diverse, microbial ecosystem, where potentially pathogenic and beneficial bacteria co-exist. Prebiotics are a good strategy to influence this composition towards a more favourable balance, by inhibiting the growth of potentially harmful or pathogenic species and promoting the bacteria having beneficial effects on host health[27]. A balanced population of gut bacteria constitute a strong intestinal barrier for the defence against pathogens, support the correct absorption of nutrients and contributes to the production of some vitamins.

Prebiotic compounds may also be added to animal feed, as an alternative to antibiotics, which for many years have been used at sub-therapeutic doses to promote growth and maintain health in farm animals, by contributing to the spread of antibiotic-resistant bacteria and the increase of enteric infections[28].

In theory any carbohydrates that enter the colon can potentially be considered prebiotic because they are potential substrates for the growth of bacteria. Polysaccharides sourced from seaweeds have been proven, through both *in vitro* and *in vivo* experiments to be excellent prebiotics[29].

Honeybee health and seaweeds

In the last decades, honey bees have been threatened by a lot of stress conditions, such as pathogens, climate change, lack of flowers and pesticides, factors which strongly affect beehive integrity and bee health[30]. Consequently, the beekeeping sector together with the whole ecosystem and the agricultural sector depending on pollinators suffer from missed pollination[31]. Among the high number of newly introduced diseases, particular attention has been focused on nosemosis, caused by an intracellular gut parasite, *Nosema ceranae,* which leads to colony weakening and collapse due to energy and nutrient deficiency[32]. Moreover, this parasite negatively influences the gut microbial symbionts and reduces the natural resistance against other pathogens[33], decreasing the efficacy of acaricide treatment used to fight the mite *Varroa destructor*[34].

Taxonomically characterized by Fries *et al*.[35], *N. ceranae* is now detected all over Europe; in Italy, it has been declared endemic since 2010. Currently, the only treatment to control nosemosis, Fumagillin-B, is forbidden in the majority of EU member states due to the absence of maximum residue limit (MRL) determination for honey[36]. More recently (2018), the manufacturer of Fumagilin-B has ceased production. Alternative therapeutic treatments such as bacteriocin, itraconazole, benzoic and acetic acids, resveratrol or *Artemisia* extract have been tested but they only resulted in a small reduction in the number of parasites, without protecting from nosemosis.

The need to find alternative treatments to fight *N. ceranae* may find a solution in the use of seaweeds and their prebiotic properties.

The gut of the honey bee, *Apis mellifera*, as well as other animals living in social communities, harbors a distinctive microbial community, composed of a taxonomically restricted set of species specific to social bees[37]. Different species possess distinct functional capabilities linked to host interaction, biofilm formation, and carbohydrate breakdown. Whereas the former two functions could be critical for pathogen defense and immunity, the latter one might assist nutrient utilization. By reinforcing the gut microbial symbionts, a general improvement of resistance to pathogens and nutrient intake may be achieved.

Actually, a study conducted by Roussel and colleagues showed the potential of algal derived polysaccharides to control honeybee nosemosis[38]. This study shows that polysaccharides derived from seaweeds allow a decrease of both parasite load and mortality rate due to *N. ceranae* infection.

Beyond the beneficial prebiotic effect of seaweeds, the nutritive and biological properties of seaweed may affect positively the bees' health, by providing the protein, mineral and vitamin content necessary for the correct growth and functionality of biochemical reactions.

HiveAlive- feed supplement for bees that contains seaweeds

The beneficial properties of seaweeds have been successfully exploited by Advance Science in the production of HiveAlive, a feed supplement containing unique seaweeds, specifically designed for bees. Results from long-term field trials show a reduction in *Nosema* spore counts, as well as an increase in colony population and honey/pollen production and decrease in overwinter mortality[39; 40; 41]. Moreover, *in-vitro* tests showed the ability of HiveAlive to inhibit both the sporulation of *Ascosphaera apis* (the fungus responsible for Chalkbrood) [42] and the growth of *Paenibacillus larvae* (the bacterium responsible for American Foulbrood) [43].

In conclusion, seaweeds represent a natural alternative sourced from the sea to feed your bees and make them healthier and stronger!

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