

ALGAE IN FOOD AND FEED

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ABSTRACT: Algae are primary producers which present a remarkable source of different nutrients. While the high protein content of various species is one of the main reasons to consider them as an unconventional source of proteins, oils from microalgae rich in some PUFAs seem particularly suitable for children, pregnant women, vegetarians and patients with fish allergies. Since algae also represent an important source of vitamins, minerals, antioxidants and natural colorants, the incorporation of the whole biomass in food and feed could be used to provide the color, increment nutritional value, and improve texture or resistance to oxidation. The incorporation of microalgae biomass in the traditional food is a way to design attractive and healthy new products. Even when used in small amounts in nutrition of different animals, algae have been credited with improving the immune system, the increasing of weight, the number of eggs, reproductive performance, or reducing cholesterol levels, indicating the possibility of new farming methods in order to improve the quality of meat and eggs. Also, their importance in aquaculture is not surprising since they are natural food for these organisms. Finally, the nature's richest and most complete source of organic nutrition, becoming a health food worldwide because of the high protein content and various bioactive compounds is microalga *Spirulina*.

Key words: *algae, food, feed, proteins, lipids, vitamins, minerals, antioxidants, colorants*

INTRODUCTION

Algae are by far the most abundant primary producers, although some can be mixotrophic or heterotrophic. In biological sense, the term algae implies more divisions of lower plants which contain chlorophyll in cells and are typical inhabitants of aquatic biotopes, although they are quite widespread outside the aquatic environment (Blazencic, 2007), and on the basis of dimensions they are divided into macroalgae (macroscopic algae) and microalgae (microscopic algae). A special group of microalgae are blue-green algae, also called cyanobacteria because of their prokaryotic cell type, identified as one of the most promising

group of organisms for the isolation of novel and biochemically active natural products (Singh et al., 2005).

Algae are cultivated and used in nutrition worldwide. They are an important source of vitamins, minerals, proteins, polyunsaturated fatty acids, antioxidants, etc. (Pulz and Gross, 2004; Svircev, 2005; Blazencic, 2007; Gouveia et al., 2008b). The strong potential of microalgae stems from the facts that they are not as well studied as agricultural crops, they can be cultivated in areas unsuitable for plants (with less or no seasonality required), and in comparison with plants, some species have severalfold higher production. Since

they utilize sunlight energy more efficiently, their potential for the production of valuable compounds or biomass is widely recognized and they can be used to enhance the nutritional value of food and feed. Microalgae combine properties typical of higher plants with biotechnological attributes proper to microbial cells. In other words, they can reproduce very fast in the liquid medium with simple nutritional requirements (they do not require an organic carbon source like fungi and bacteria) and accumulate some metabolites. However, of particular importance is the possibility to increase production of biomass or desired compounds by manipulating the cultivation conditions. For example, the lack of nitrogen compounds in the medium of microalga *Chlorella* can lead to lipid accumulation of 85% in biomass (Blazencic, 2007), or mixotrophic cultivation of microalga *Spirulina* can increase productivity 5.1-fold (Chen and Zhang, 1997). Considering enormous biodiversity and developments in genetic engineering, microalgae represent one of the most promising biological resource for new products and applications (Pulz and Gross, 2004)

CHEMICAL COMPOSITION OF ALGAE

The chemical composition of different algae is presented in Table 1 (Becker, 2007; Chisti, 2007). The high protein content of various microalgal species is one of the main reasons to consider them as an unconventional source of proteins, and as microalgae are capable of synthesizing all amino acids, they can also be a source of the essential ones. Moreover, the average quality of most examined algae is equal,

sometimes even superior in comparison to conventional plant proteins (Becker, 2007). For example, dried *Spirulina* biomass contains all the essential amino acids and about 68% of biomass present proteins, which is a threefold higher content than in beef. Another microalga, *Chlorella*, contains about 50–60% of proteins, whose quality is comparable to the proteins of yeast, soy flour and milk powder (Blazencic, 2007). Milovanovic et al. (2012) investigated the protein content in dry biomass of several cyanobacterial strains originating from Serbia, and the results showed that all of them possess very high values, ranging from 42.8% to 76.5%.

Algae also have a high fibre content (Plaza et al., 2008). Polysaccharides like agar, alginates and carrageenans 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 (Pulz and Gross, 2004), or possessing a potential antiviral activity (Hemmingson et al., 2006).

Oil content in microalgae can exceed 80% by weight of dry biomass, while levels of 20–50% are quite common (Chisti, 2007), and owing to these levels, some microalgae are considered to be one of the best sources for biodiesel production. Solazyme (USA) produces microalgal oils for different applications, including human nutrition.

Table 1.
Chemical composition of different algae (w/w)

Alga	Proteins	Carbohydrates	Lipids
<i>Aphanizomenon flos-aquae</i>	62	23	3
<i>Chlorella pyrenoidosa</i>	57	26	2
<i>Chlorella vulgaris</i>	51–58	12–17	14–22
<i>Porphyridium cruentum</i>	28–39	40–57	9–14
<i>Schizochytrium</i> sp.	-	-	50–77
<i>Arthrospira maxima</i>	60–71	13–16	6–7

Source: Adapted from Becker (2007) and Chisti (2007)

ALGAE AS A SOURCE OF POLYUNSATURATED FATTY ACIDS (PUFAs)

Among all PUFAs some of the ω -3 are of particular interest, and the most important nutritionally are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Also, gamma linolenic acid (GLA) is an ω -6 PUFA, a very important precursor in the synthesis of prostaglandins. Clinical trials have shown that GLA helps in the treatment of diseases such as arthritis, heart disease, obesity, alcoholism, depression, schizophrenia, Parkinson's disease, multiple sclerosis, zinc deficiency and some symptoms in elderly population (Kerby and Stewart, 1987). Unsaturated fatty acids affect hyperlipidemia by lowering lipid levels (cholesterol and triglyceride), and thus reduce the risk of heart disease and atherosclerosis. In this respect, EPA and GLA are extremely effective (Richmond, 1986; Kerby and Stewart, 1987).

Although EPA and DHA are typically extracted from fatty fish, there are many problems of using this source: 1) mercury and polychlorinated biphenyl levels are often unacceptable for certain consumers (especially children and pregnant women; the developing nervous system of the fetus is very susceptible to even low levels of these contaminants); 2) an unpleasant odor; 3) they are not suitable for vegetarians; 4) the problem of sustainability of fish as a source (many species have been fished almost to extinction and we are on course to eliminate the world's supply) (Spolaore et al., 2006; Cannon, 2009). On the other hand, fish obtain their ω -3 from the diet rich in algae, which are the initial producers of PUFAs in the aquatic food chain. Since microalgae can reach much higher contents and productivities in comparison to other possible sources, PUFAs of microalgal origin have a very promising biotechnological market for food and feed. The infant formulae industry appears to be particularly suitable. DHA is an absolutely essential nutrient for the developing fetal brain and also crucial for optimal retinal function in infants (McCann and Ames,

2005). Although it occurs naturally in breast milk it is absent from cow's milk, and a number of health and nutrition organizations specifically recommended the inclusion of DHA in infant formula for pre-term and full term infants (Spolaore et al., 2006). Martek (USA) has developed and patented two fermentable strains of microalgae which produce oils rich in DHA—*life'sDHA*[™]. This oil comes from a source that has not been genetically modified, it is accepted by the FDA for use in U.S. infant formulas, and it is the only DHA currently used in U.S. infant formulas. There are also many *life'sDHA* supplements, as well as many food products. Lonza (Switzerland) produces DHAid[™], the vegetarian source of DHA, from naturally occurring microalgae. It is available in different concentrations and for various applications. V-Pure is also an algal product, the vegetarian source of both EPA and DHA in the capsule form, certified and approved by the vegetarian society. Microalgal oils seem to be a good solution particularly for children, pregnant women, vegetarians and patients with fish allergies.

Gouveia et al. (2008a) incorporated biomass of *Isochrysis galbana*, microalga rich in the long chain ω 3-PUFA (LC-PUFAs- ω 3), especially EPA and DHA in biscuits. Biscuits presented LC-PUFAs- ω 3 levels (EPA+DPA+DHA) of 100 mg/100g and 320 mg/100g, for 1% and 3% microalgal biomass incorporation, respectively, which reflect an important source of PUFA- ω 3 with moderate biscuit consumption. The thermal resistance of fatty acids should be due to their presence in an encapsulated form inside the microalga. The incorporation of biomass resulted also in the enhancement of texture properties and the high stability of color and texture. Also, feeding hens with special microalgae to produce "OMEGA" eggs has proved to be commercially profitable (Pulz and Gross, 2004).

Milovanovic et al. (2011) investigated the fatty acid composition of several cyanobacterial strains originating from Serbia. The results showed that 16 carbon and 18 carbon chain fatty acids represent the

most significant constituents. Also, the content of the relatively rare GLA was the highest in the *Spirulina* strains, while in the *Nostoc* strains depended on the growth medium used. According to WHO/FAO experts, the ratio of PUFA/SFA for a “balanced diet” is above 0.4, and in this view all investigated strains showed a favourable ratio, ranging from 1.65 to 3.71 (Milovanovic et al., 2012).

ALGAE AS A SOURCE OF VITAMINS AND MINERALS

Algae represent a rich source of vitamins and minerals, which makes them particularly suitable as nutritional supplements. Some species of *Chlorella* genus contain more vitamins than most cultivated plants (Blazencic, 2007). Also, *Spirulina* genus contains over tenfold more β -carotene than any other food, including carrots (Mohammed et al., 2011) and more vitamin B₁₂ compared to any fresh plant or animal food source. Compared to green algae, spinach and liver, this genus represents the richest source of vitamin E, thiamine, cobalamine, biotin and inositol (cited by Gantar and Svircev, 2008). Several microalgal species produce α -tocopherol (α -T, the most biologically active form of vitamin E) in very high concentrations. Rodriguez-Zavala et al. (2010) found that the production of α -tocopherol in heterotrophically grown microalga *Euglena gracilis* after 120 hours reach 3.7 ± 0.2 mg/g, which is in comparison to sunflower, soybean, olive and corn (some of the most common natural sources of vitamin E) about 13, 18, 95 and 56 fold higher productivity, respectively. Also, if the reported high biomass yields of the microalga *Tetraselmis suecica* can be reached, it could compete with *E. gracilis* as a candidate for commercial α -T production (Carballo-Cardenas et al., 2003). In the six seaweeds (macroscopic marine algae) species examined by Rodriguez-Bernaldo de Quiros et al. (2004) the amount of folate (as folic acid) ranged to 161.6 μ g/100 g dry mass.

Algae also have potential as mineral additives in the animal feed industry. The ash content of filamentous green algae ranged from just under 12% to one sample of *Cladophora*

that had over 44% (Hasan and Chakrabarti, 2009). Some edible macroalgae contained higher amounts of both macrominerals (8.083–17,875 mg/100g; Na, K, Ca, Mg) and trace elements (5.1–15.2 mg/100 g; Fe, Zn, Mn, Cu) than those reported for edible land plants, so that they could be used as a food supplement to help meet the recommended daily intake of some essential minerals and trace elements (Ruperez, 2002).

However, according to Shields and Lupatsch (2012) algal biomass mainly offers a supplementary source rather than a complete replacement for manufactured minerals or vitamins in animal feeds.

ALGAE AS A SOURCE OF ANTIOXIDANTS

In algae, antioxidants belong to compounds of the major interest (Plaza et al., 2008). Microalgal biomass may be considered as a multi-component antioxidant system, which is generally more effective due to the interactions between different antioxidant components (Gouveia et al., 2008b). The most powerful water-soluble antioxidants found in algae are polyphenols, phycobiliproteins and vitamins (Plaza et al., 2008). Being photosynthetic organisms, algae are exposed to light and high oxygen concentrations, and in cultures with high cell density in closed photobioreactors, oxygen concentrations can be very high. Such conditions promote the accumulation of highly effective antioxidative scavenger complexes to protect cells, and for example, the antioxidative potential of *Spirulina platensis* can increase 2.3-fold during oxygen stress (Pulz and Gross, 2004). For functional food/nutraceuticals, the radical-scavenging capacity of microalgal products is of growing interest, especially in the beverage market segment (Pulz and Gross, 2004).

ALGAE AS A SOURCE OF NATURAL COLORANTS

Synthetic colors used in food industry are mainly coal tar derivatives and although they are banned in many countries because of health risks, these colors are preferred due to the low yield of natural colors from plant sources (Mohammed et

al., 2011). Since the world trend for colorants is to substitute artificial for natural ones and extraction from plants requires greater amount of biomass, algae present a good alternative. Besides chlorophylls, other types of pigments can be found in algae, such as carotenoids and phycobiliproteins.

In Brazil, chlorophyll used as a natural colorant is obtained from spinach with the content of approximately 0.06 mg/g, whereas the *Spirulina* sp. biomass contains 1.15 mg/g (Danesi et al., 2002). Using KNO₃ and NH₄Cl as a source of nitrogen in media, Rodrigues et al. (2010) obtained high-quality *Spirulina* biomass with the chlorophyll content of 21.85 mg/g. On the other hand, according to Danesi et al. (2002), the incorporation of the whole *Spirulina* sp. biomass in food is particularly interesting because it will provide green color and also increment the nutritional value. Some algae are a rich source of carotenoids, used as natural food colorants, an additive for feed, vitamin supplements and health food products. For pigmentation purposes of broilers and/or egg yolks carotenoids must be contained in the diet, and according to Gouveia et al. (1996) the effect of these pigments from *Chlorella vulgaris* biomass upon the pigmentation of egg yolk was comparable with the commercially synthetic pigments used. The most important carotenoid is β -carotene because it is the most active as provitamin A, and it is used as a colorant, a provitamin, an additive to multivitamin preparations and a health food product under the antioxidant claim. The natural form of this pigment has a stronger effect than the synthetic one, from which it is several fold easily absorbed by the body. Although the richest known food source of this carotenoid is *Spirulina*, the most important microalga for natural production on the large scale is *Dunaliella salina* with an accumulation up to 16%/dry weight (Del Campo et al., 2007). Products derived from *D. salina* are β -carotene extracts, *Dunaliella* powder for human use, for feed use (Spolaore et al., 2006), and preparations as a complete source of carotenoid nutrition. There are increasing evidences suggesting that astaxanthin surpasses the

antioxidant benefits of β -carotene, vitamin C, vitamin E and many xanthophylls. This carotenoid is used in aquaculture as a pigmentation source, as well as in nutraceuticals and food and feed industries. Although the natural form cannot compete commercially with the synthetic one, it is preferred for few particular applications, and microalga *Haematococcus pluvialis* represents a rich source cultivated on the large scale (Svircev, 2005; Spolaore et al., 2006). Fraunhofer IGB (Germany) is concentrating its activities on two markets in the food supplement sector, including natural astaxanthin derived from this microalga (www.igb.fraunhofer.de). Phycobiliproteins are a group of pigments with the commercial value found only in algae, but not in all divisions of algae. Although they are used as natural dyes, there are also evidences of many health-promoting properties. Phycocyanin is one of the most promising commercial substances in *Spirulina*, which is produced in Japan as a natural food colorant marketed under the name Lina-blue. It is used in Japan and China in food products like chewing gums, candies, dairy products, jellies, soft drinks, etc (Gouveia et al., 2008b). It was shown that phycocyanin possesses an antioxidant, anti-inflammatory, neuroprotective and hepatoprotective activity, but also appears to be a potential chemotherapeutic, as well as a hypocholesterolemic agent (cited by Gantar and Svircev, 2008). Simeunovic et al. (2012) investigated the production of phycobiliproteins in cyanobacterial strains originating from Serbia, and the results showed that some tested strains represent an excellent source of one or more phycobiliproteins. Since the content and composition of phycobiliproteins depend on environmental factors, Simeunovic et al. (2013) examined the impact of some of them. The results suggested that in tested terrestrial, N₂-fixing *Nostoc* and *Anabaena* strains nitrogen availability affected composition of phycobiliproteins. Also, the results showed significantly lower pigment concentrations in strains exposed to dry and dark conditions.

Microalgal pigments, as well as the whole biomass can be used to color food and feed, and also to improve textural para-

meters. It is showed that phycocyanin significantly improved emulsions rheological properties, which increased linearly with the phycocyanin concentration (Batista et al., 2006). On the other side, due to the antioxidant properties of natural pigments, it is also possible to improve the resistance to oil oxidation, which is particularly advantageous in high fat products like emulsions (Gouveia et al., 2008b). The incorporation of microalgal biomass in emulsions by Gouveia et al. (2006) resulted in a wide range of appealing colors from green to orange and pink, and also enhanced resistance to oxidation. The authors also compared the effects of *Haematococcus pluvialis* and *Chlorella vulgaris* biomass, and assumed that a higher oxidation stability in presence of *H. pluvialis* could be due to astaxanthin as a dominant carotenoid.

ALGAE AS A COMPONENT OF FUNCTIONAL FOOD

In developed countries, the diet is highly caloric and in combination with the modern style of life leads to health problems, such as obesity, heart diseases, diabetes, etc. Therefore, there is a need for food products that can promote health by enriching the diet with vitamins, minerals, PUFAs, etc., and according to consumers using the natural forms of ingredients instead of the synthetical ones has become very appealing.

Algae represent a remarkable, but a poorly explored natural source of compounds with biological activity. The most important substance in *Chlorella* seems to be beta-1,3-glucan, which is an active immune-stimulator, a free-radical scavenger and a reducer of blood lipids (Spolaore et al., 2006). The cyanobacterial role as an antibacterial, antiviral, antitumor and food additive have been well-established (Singh et al., 2005) and the most promising aspect of microalgal biotechnology is a successful drug discovery (Spolaore et al., 2006). The role of antioxidants found in algae is already mentioned above in the text, but there are also studies on the hypocholesterolemic effect which is attributed to different compounds, such as the activity of lipoprotein lipase, chlorophyll

content (cited by Singh et al., 2005), and C-phycocyanin (cited by Gantar and Svircev, 2008). In a group of rats fed with the mixture of several algae, serum total cholesterol, LDL cholesterol, free cholesterol, and triacylglycerol levels were significantly reduced to 49.7%, 48.1%, 49.0% and 74.8%, respectively, of those of the control, which was associated with polysaccharides (Amano et al., 2005). Studies with chicken fed with microalga *Porphyridium* sp. biomass at 10% diet incorporation lowered the serum cholesterol levels by 28%, while egg yolk tended to have reduced cholesterol levels by 10% and increased the linoleic acid and arachidonic acid level by 29% and 24%, respectively. In addition, the color of egg yolk became darker as a result of the higher carotenoid levels (2.4 fold higher for chicken fed with 5% supplement) (Ginzberg et al., 2000). There are also investigations of *Spirulina* prebiotic effects which led to at least a 10-fold increase in the growth rate of the lactobacilli compared with the control (Pulz and Gross, 2004).

Microalgal biomass was predominately utilized in the health food market. However, since the incorporation of ingredients with the natural origin and functional properties in the traditional food is a way to design attractive and healthy new products, there are numerous combinations of microalgae or mixtures with other foods all over the world.

ALGAE IN HUMAN NUTRITION

During past decades, the increase in the world's population led to a search for a new alternative food, and algal biomass appeared at that time as a promising source. In 1978, a study was carried out with a malnourished infant receiving a diet enriched with algae. The authors concluded that the significant improvement in the state of the health was attributed not only to algal proteins but also to therapeutic factors (cited by Gouveia et al., 2008b).

In coastal areas of all continents, seaweeds are used in human and animal nutrition, so that they are widely cultivated algal crops. Species such as *Porphyra* sp., *Chondrus crispus*, *Himanthalia elongata*

and *Undaria pinnatifida* are very interesting to consumers and the food industry due to their low content in calories and high content in vitamins, minerals and dietetic fibre (Plaza *et al.*, 2008). On the other hand, microalgal biomass is usually available in a form of powder, tablets, capsules, liquids and, also, it can be incorporated into different food products. However, the consumption of microalgal biomass is restricted to very few taxa and the most important in human nutrition are *Spirulina* and *Chlorella* genera.

Spirulina is the richest and the most complete source of organic nutrition in nature, becoming health food worldwide because of the high protein content and various bioactive compounds. It has been used as food by local populations in Mexico and

Africa since ancient times, and currently it is used as a human nutritional supplement, as well as feed supplement in aqua-

culture, the aquarium and poultry industries (Hasan and Chakrabarti, 2009).

The species of the genus *Chlorella* are known as traditional food in the Orient. This genus is used in the healthy food market, as well as for feed and aquaculture. In addition, *Spirulina* has various possible health promoting effects, while *Chlorella* is important as a health promoting factor concerning many kinds of disorders (Gouveia *et al.*, 2008b).

Since the cellulosic cell wall possesses a serious problem in digesting/utilizing the algal biomass, several authors demonstrated an important role of its processing (Becker, 2007). The lack of polysaccharides present in the eukaryotic algae cell wall in the cell wall of cyanobacteria makes their biomass more easily digestible and therefore more acceptable for human consumption (Richmond and Preiss, 1980).

Table 2.

Major microalgae commercialized for human nutrition

Alga	Annual production (t/year)	Producer country	Applications and products
<i>Spirulina (Arthrospira)</i>	3000	China, India, USA, Myanmar, Japan	Human and animal nutrition, cosmetics (phycobiliproteins, powders, extracts, tablets, beverages, chips, pasta, liquid extract)
<i>Chlorella</i> sp.	2000	Taiwan, Germany, Japan	Human nutrition, aquaculture, cosmetics (tablets, powders, nectar, noodles)
<i>Dunaliella salina</i>	1200	Australia, Israel, USA, China	Human nutrition, cosmetics (β -carotene, powders)
<i>Aphanizomenon flos-aquae</i>	500	USA	Human nutrition (capsules, crystals, powder)
<i>Haematococcus pluvialis</i>	300	USA, India, Israel	Aquaculture, astaxanthin
<i>Cryptocodinium cohnii</i>	240t DHA oil	USA	DHA oil
<i>Shizochytrium</i> sp.	10t DHA oil	USA	DHA oil

Source: Adapted from Spolaore *et al.* (2006) and Gouveia *et al.* (2008b)

Prior to commercialization, algal material must be analyzed for the presence of toxic compounds. Recommendations have been published by different international organizations and additional national regulations often exist. They concern nucleic acids, toxins and heavy-metal components (Spolaore et al., 2006). Food safety regulations for human consumption are the main constraint for the biotechnological exploitation of microalgal resources. In Table 2 (Spolaore et al., 2006; Gouveia et al., 2008b) there are listed major microalgae commercialized for human nutrition.

Food companies have started serious activities to market functional foods with microalgae and cyanobacteria, such as pasta, bread, cakes, salad sauces, ice cream, pudding, yogurt and other milk products, and soft drinks (Pulz and Gross, 2004; Svircev, 2005). Particularly cost-efficient is beer production based on the spirulina biomass, marketed under the name "Spirulina beer" and "Anti-age beer" (Svircev, 2005).

ALGAE IN ANIMAL NUTRITION

Numerous nutritional experiments clearly indicate the high nutritional value of microalgae in the diet of pigs, cows, sheep, chicken and other domestic animals, as well as many aquatic organisms (in aquaculture) (Svircev, 2005). In most studies to date, algae are not considered as an essential feed source due to the need of large amounts of biomass, but even when used in small amounts, algae have been credited with improving the immune system, lipid metabolism, gut function, stress resistance (cited by Shields and Lupatsch, 2012), as well as increasing of appetite, weight, number of eggs, reproductive performance or reducing cholesterol levels (Svircev, 2005). A large number of nutritional and toxicological evaluations demonstrated the suitability of algae biomass as a valuable feed supplement or a substitute for conventional protein sources (soybean meal, fish meal, etc.). The target domestic animal is poultry, mainly because the incorporation of algae into poultry rations offers the most promising prospect for their commercial

use in animal feeding (Becker, 2007). In poultry, algae can be used as a partial replacement for conventional proteins with the incorporation of 5–10% (Spolaore et al., 2006). Also, according to Gouveia et al. (2008b), they may serve as almost the sole protein source in laying hens, and in several countries, they are officially approved as chicken feed. In pigs ration, Yap et al. assumed the incorporation of even 33%, without negative symptoms (Gouveia et al., 2008b). However, it should be expected that the most suitable for feeding with algae are ruminants, because they are able to digest even an unprocessed algal cell wall (Gouveia et al., 2008b). Pet food market is also very promising (Pulz and Gross, 2004). Research results indicate the possibility of new farming methods in order to improve the quality of meat and eggs, and it may also be considered in order to lower the cholesterol level in blood and egg yolks. Large world's chicken and rabbit farms have excellent results using microalgae in the diet of these animals, so that their use in many animal farms is increasing worldwide (Svircev, 2005). According to Adarme-Vega et al. (2012) several companies have shifted their focus from algal biodiesel production to high value products such as ω -3 and protein rich biomass as animal feed (e.g. Aurora Algae, MBD, Cellana).

Microalgae are a source of food and a dietary supplement in the commercial cultivation of aquatic organisms. Their importance in aquaculture is not surprising considering the fact that they are natural food for these organisms. Using some species of microalgae in the diet of fish fry lowers their price to 50%, and in order to obtain a higher nutritional value of microalgal biomass, it is often used a combination of two or more species (Svircev, 2005). Genus *Spirulina* is widely used as a feed additive in the Japanese fish farming industry, with inclusion levels 0.5–2.5% (Hasan and Chakrabarti, 2009). Sturgeon fed with *Spirulina*-based feed even outperformed those receiving fish meal-based diets (Palmegiano et al., 2005).

Recently, attention has been drawn to the microalgae *Isochrysis galbana* and *Diacro-*

nema vlkianum due to their ability to produce long chain PUFA, mainly EPA and also DHA that are accumulated as oil droplets (Gouveia et al., 2008b).

CONCLUSIONS

Considering the fact that microalgae are poorly explored, their cultivation can be independent of external conditions, more efficient convert solar energy and in comparison with higher plants, they do not require fertile soil, produce a wide range of substances, can be used for different applications and some species reproduce very fast, so that these organisms present a really remarkable source of biomass and certain compounds. An advantage of particular importance is the possibility to regulate and define metabolism and the production of the target compound by manipulating the cultivation conditions. While a mixture of different species or combinations with other food opens up many possibilities, their use in feed can also solve the issue of using certain plants which are, in the first place, used as a food. Also, they can lower the price of animal feeding. Manufacturers of these organisms worldwide have recognized different potentials and therefore focused just on the food and feed industry.

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АЛГЕ У ИСХРАНИ ЉУДИ И ЖИВОТИЊА

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Сажетак: Алге су далеко најзаступљенији примарни продуценти и представљају изванредан извор различитих нутритивно вредних једињења. Док је висок садржај протеина код разних врста, један од главних разлога због којих се сматрају неконвенционалним извором протеина, уља која се добијају из микроалги са високим садржајем одређених ПУФА би могла бити посебно погодна у исхрани деце, трудница, вегетаријанаца и пацијената алергичних на рибу. Алге такође представљају богат извор витамина, минерала, антиоксиданата и природних колораната, тако да се инкорпорацијом целокупне биомасе у храну поред бојења може повећати хранљива вредност, али и побољшати текстура или отпорност на оксидацију. Инкорпорација биомасе микроалги у традиционалну храну је начин да се дизајнирају атрактивни и здрави нови производи. У исхрани различитих животиња, чак и када се користе у малим количинама, алгама је приписано јачање имуног система, повећање тежине, броја јаја, репродуктивних својстава, снижење нивоа холестерола, итд., што указује на могућност нових метода узгајања у циљу побољшања квалитета производа животињског порекла. Њихов значај у аквакултури је такође познат с обзиром на то да су природна храна ових организама. Коначно, најбогатији и најпотпунији природни извор органске исхране који постаје све популарнији широм света због високог садржаја протеина и разних биоактивних једињења је управо микроалга спиролина.

Кључне речи: *алге, храна, протеини, липиди, витамини, минерали, антиоксиданси колоранти*

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