The possibilities of the application of algal biomass in the agriculture

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Please cite as: CHEMIK 2012, **66,** 11, 1235-1248

Introduction

The use of algal biomass, which is a renewable source of many valuable active substances with a wide range of applications in agriculture, includes sustainable agriculture and manufacturing and meets both economic and ecological objectives, considered as a protection against contamination and risks from agricultural activities.

The size of the productivity of microalgal biomass is determined now as 5 thousand tons per year (dry weight), which gives the market value of $500MM [1, 2]. Because of these nutrients and the values of feeds, microalgae can be incorporated into the diets of various animals, fish, domestic animals and in animal breeding [3, 4, 5].

The use of algae as feed materials for animals is more common than their use in the human diet. A large number of nutritional and toxicological evaluations showed the algal biomass could be used as a valuable feed supplement, which can successfully replace conventional sources of protein (soy, fish meal, rice bran, etc.) [6]. Seaweeds are also a source of dietary minerals such as sodium, potassium, iodine as well as fibre. Another potential area, where the use of seaweeds becomes important, is their supplementation in order to improve the texture of foods.

Micro- and macroalgae

The algae can be divided into two groups: microalgae and macroalgae (seaweed). They differ in nutritional value and methods of collection. Figure 1 shows the differences between them.

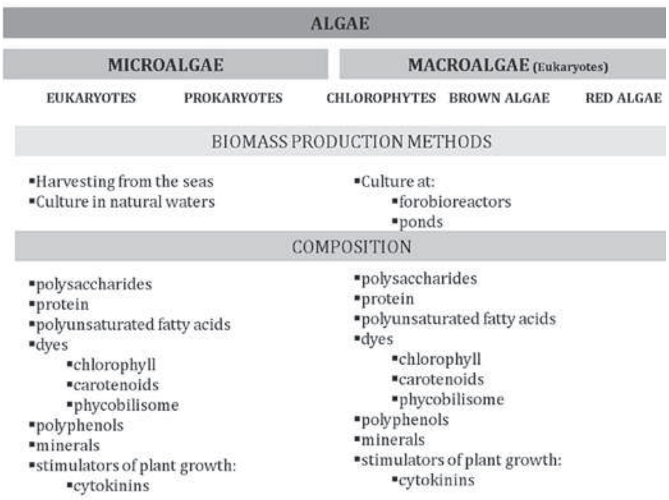

Fig. 1. Division of algae in two groups: microalgae and macroalgae [7, 8]

Algae in animal nutrition

In Europe, seaweeds have been used as animal feed since Roman times. In Iceland, France and Norway pets were fed by algae in order to increase the nutritional value of feed [9, 10]. In 2004, the use of algae as animal feed accounted for 1% of the global industry based on seaweed ($10MM in the U.S., mainly *Ascophyllum nodosum*) [11]. In the case of microalgae used as feed additives, the value of industry in the same year in the U.S. totalled $300MM [12]. There are about ten thousand identified species of algae and about 5% is used as food for humans or animals.

Polish Minister of Agriculture and Rural Development authorizes the use of algae as a feed material [13]. In the list of feed materials, which have been authorized under the provisions of the European Union, algae were listed as feed material [14].

The literature describes the nutritional characteristics of algae, taking into account their use in the nutrition of marine animals, such as: oysters, fish (e.g., bream – a species of fish, which have been classified into families of finfish) [3÷5, 15÷17]. In the feeding of farm animals, the main target is the poultry, mainly because of the dose of algae in the diet of poultry, which is the most promising prospect for their commercial application. Another growing market is the use of algae in aquaculture. It is estimated that about 30% of current world production of algae is sold as feed material. In Table 1, nutritional experiments using macro-and microalgae as feed additives were listed.

Algae can serve as source of many nutrients functions. In addition, it is known that the different families of marine algae produce a variety of secondary metabolites, which form the basis for the defence against many herbivores. Hardt et al. (1996) presented the results of research on the deterrent properties produced by *Dictyota acutiloba* designed to scare the fish from tropical and temperate zones [47].

The work of Sheih et al. (2009) showed that low-cost algal waste protein can be a new alternative for the production of peptides with antioxidant properties. Waste protein from algae is usually used as animal feed, a by-product in the production of extracts from microalgae *Chlorella vulgaris*. Algal waste protein can be subjected to the hydrolysis using for example pepsin. Post-extraction residues, which contain over 50% protein, have a low commercial value, but still can be a valuable source of protein in animal feed. The study indicated that the waste from algae could become a new source of antioxidants [48].

It was shown that two products rich in polyunsaturated fatty acids ω–3 (type Aquagrow-DHA and the type of TV-20 *C. cohnii*) derived from edible seaweed, have inhibitory effects on methane production by ruminants. It has long been known that the production of methane (CH_4) by ruminants decreases the energy efficiency of production of milk and beef. In addition, the recent increased interest in reducing methane production by ruminants is one of the strategies to reduce greenhouse gas emissions [49].

Macroalgae are a source of polyphenolic compounds that have well documented antioxidant and antibacterial properties. This is used as food additives to prevent unwanted spoilage of meat products.

Table 1

The application of algae in animal feeding (M – Microalgae, Macroalgae: G – Green, B – Brown, R – Red)

Alga	Active substance	Animal	Dose	Effect	Ref.
Schizochytrium sp. (M)	Docosahexaenoic acid (DHA)	Pigs	0.25%–0.5 %	A significant increase of DHA.	[18]
Hematococus pluvalis (M)	Astaxanthin	Broilers	0.350, 1 800 and 8 950 mg/kg	Antibacterial activity of astaxanthin to *Capylobacter* and *Clostridium perfiringens*.	[19]
Chlorella sp. (M)	Protein	The chicks and broilers	6% and 15%	Addition of algae had no adverse effect on the biomass growth.	[20]
Nannochloropsis oculata (M)	Fatty acids and carotenoids	Laying hens	20%	Addition of microalgae increased content of unsaturated fatty acids and carotenoids in the egg yolks.	[21]
Crypthecodinium cohnii (M)	Biomass	Ducks (*Cairina moschata domestica* L.)	0.5%	Addition of microalgae did not affect the weight gain and manure characteristics as well as chemical composition, color, pH, shelf life, the aromatic characteristics of breast muscle.	[20]
Spirulina platensis (M)	Biomass	Broilers	14 and 17%	Addition of microalgae did not affect the mass, composition and histopathology of organs. Meat quality did not change. More intense color was observed.	[22]
Chlorella sp. (M)	Biomass	Laying hens	12%	Addition of 120 g of microalgae/kg of feed did not affect the quality of eggs and feed utilization. High concentrations of algae in the feed caused a more intense yellow color of egg yolks.	[23]
Schizochytrium sp. (M)	Fatty acids	Laying hens	2%	Algae as a source of *n*–3 PUFAs administered for 8 weeks had no adverse effect on the organoleptic properties.	[24]
Laminaria digitata (B), *Laminaria hyperborea* (B), *Entermorpha intestianalis* (G)	Biomass	Sheep	3–5 kg of fresh biomass per day (WM)	The sheep grew up very well, therefore macroalgae may be used as an alternative source of food.	[25]
Ulva lactuca (G)	Biomass	Goat	NR (Not Reported)	The study evaluated the nutritional value of food by checking the digestibility of organic matter in *in vitro* experiments and the decomposition of organic matter and crude protein in rumen by *in sacco* experiment. In the rumen, 85% of organic matter was decomposed. The macroalgal energy content (10.2 MJ/kg dry mass – DM) is comparable to the energy value of medium–quality hay.	[26]
Macroalgae (the species were not indicated)	Biomass	Lamb	1% DM	Animals fed with fodder with addition of macroalgae, consume more feed/kg of body weight but weight gain was smaller than in the control group. Addition of macroalgae affected the growth of hot carcass weight.	[27]
Ulva lactuca (G)	Biomass	Ruminants	20% DM	*Ulva* as a low-energy and rich in nitrogen macroalga, may be a component of the feed, consisting of cereals, which are high-energy material with the low content of nitrogen.	[28]
Laminaria digitata (B)	Biomass	Piglets	0.12 and 0.19% DM	The bioavailability of iodine from macroalga and KI (added in the same amounts) was compared. There was a significant increase in iodine content in the organs (muscle, liver, kidney, heart) when macroalga was added to the feed. Organic form proved to be more digestible for pigs than inorganic forms.	[29]
Pithophora sp. (G)	Biomass	Laying hens	7.5%	The mixture of *Hydrilla verticillata* Rich and macroalga *Pithophora sp*. influenced positively the yellow color of egg yolks, however, there was no difference in egg production, in feed conversion, in increase of spleen weights, compared with the corn-soybean feed, which was used as a reference.	[30]
Fucus serratus (B), *Fucus esiculosus* (B)	***Fucoxanthin***	Laying hens	15% DM	The addition of macroalga caused the increase of the concentration of metabolites of ***fucoxanthin by 15–20% in egg yolks.***	[31]
Enteromorpha sp. (G)	*n*–3 fatty acids	Laying hens	10% DM	Addition of algae had no effect on egg production, feed intake, egg weight and thickness of egg shells. Cholesterol content of eggs in the experimental group was 5% lower than in the control group.	[32]
Ulva rigida (G)	Biomass	Poultry	10, 20, 30% DM	With the increase of macroalgae content in the feed, feed intake and growth rate decreased.	[33]
Enteromorpha intestinalis (G), *Ulva lactuca* (G), *Ulva taeniata* (G), *Caulerpa taxifolia* (G), *Codium flabellatum* (G), *Codium iyengarii* (G), *Halimeda tuna* (G), *Bryopsis pennata* (G), *Caulerpa scalpeliformis* (G)	Biomass	Poultry	10, 20 and 30% WM	The best results were noted in the group with addition of 10% of algae, where the largest increase in body mass, decrease of fat content, increase of protein content in the blood and liver was observed when compared to control group.	[34]
Ulva sp. (G), *Hypnea charoides* (R), *Colpomenia sinuosa* (B), *Sargassum hemiphyllum* (B)	Biomass	Rats	5% DM	Macroalgae have no negative impact on growth of rats – body weight and organs, except of *C. sinuosa*, which influenced significantly to the mass of the kidney. Moreover, in rats fed with algae, increase in high-density lipoprotein (HDL) and triglycerides was observed. *Ulva* sp. and *H. charoides* reduced the total cholesterol level.	[35]
Porphyra tenera (R), *Undaria pinnatifida* (B)	Biomass	Rats	15% DM	*Undaria* influenced significantly the growth of the rats. Macroalgae can also provide a rich source of dietary fiber and minerals.	[36]

Porphyra tenera (R), *Laminaria digitata* (B)	Biomass	Rats	7% DM	In rats fed with the algal additive, better absorption of minerals was observed than in the control group. No effect of algae on the mass of organs was noted.	[37]
Laminaria angustata (B)	Biomass	Rats	20% DM	There was no difference in the feed intake by the rats in the control and algal group. However, the wet weight of rat droppings in the second group was significantly higher than in the control group, which is associated with a higher intake of dietary fiber, which is present in algae. There was also an increase in weight of the cecum, small and large bowel in rats fed with algae.	[38]
Ulva reticulata (G)	Fatty acids	Mice	5 and 10% DM	Addition of macroalgae caused an increase in fatty acid content in serum and liver. With the increase of algae content in the feed (from 0.5 to 10% DM), a significant decrease in triglyceride concentrations in liver and serum was observed.	[39]
Ulva rigida (G), *Gracilaria bursa-pastoris* (R), *Gracilaria cornea* (R)	Protein	Fish – *Dicentrarchus labrax*	10% DM	Addition of each of macroalgae had no negative effect on the growth rate and utilization of nutrients. An increase of protein content, lipid and ash in the internal organs was noted.	[40]
Cladophora glomerata (G)	Protein	Fish – *Sarotherodon niloticus*	5, 10, 15, 20, 25% DM	Macroalga was a rich source of protein in feed for fish. With the increase of algal content in the feed, increased the feed conversion rate, however, decreased weight gain. An increase of total protein content in meat of fish was observed.	[41]
Ascophyllum (B)	Biomass	Fish – *Pagrus major*	2.5 and 5% DM	The increase of the content of total protein in fish feed with algal additives.	[42]
Ulva pertusa (G)		Fish – *Pagrus major*	5% DM	Addition of macroalgae to the fish diet did not affect the growth rate and feed efficiency. The decrease of fatty acids, lipids and sugars content in serum was observed.	[43]
Undaria penatifida (B), *Ascophyllum nodosum* (B)	Fatty acids	Fish – *Chrysophrys major*	5 and 10% DM	The highest growth rate and feed efficiency were observed when adding 5% of the *U. penatifida*, 5% *A. nodosum*, 10% of *U. penatifida* and finally 10% of *A. nodosum*. For the first three additives, increased lipid content in muscles was observed.	[44]
Enteromorpha sp. (G)	Biomass	Fish – *Siganus canaliculatus*	10, 20, 30% DM	Fresh biomass of macroalgae positively influenced survival, weight gain, feed consumption, increase of the content of crude protein and fat in fish.	[45]
Cladophora glomerata (G)	Carotenoids	Fish – *Oncorhynchus mykiss*	0.00045 and 0.0009 % DM	Increased content of carotenoids in meat.	[46]

Algae as fertilizers

In the recent years, the growing use of seaweed extracts as fertilizer in the ecological farming has been observed. Algal extracts contain plant hormones, amino acids, fatty acids and trace elements responsible for controlling plant growth and development and for improving the resistance to pathogens [50]. In the literature, there are data supporting the positive effects of algae and algal extracts on the growth of vegetables, fruits and other crops. Algal extracts are used both: for conditioning seeds or as fertilizers for soil or foliar application during the growing season and flowering. They stimulate seed germination, growth and yield of different crops [51, 52, 53]. The number of treatments depends on the individual susceptibility of the crop – treatments can be performed several times during the growing season. The time between successive treatments should not be longer than 14 days [53].

The influence of algae on soil

In the ecological organic farming, it is proposed to improve the soil fertility through the fertilization with compost, which contains addition of algae. Seaweed and algal extracts also have a positive impact on the soil state by improving the soil moisture holding capacity [54] and by promoting the growth of beneficial soil microorganisms [52]. Algae very well interact with isolated from soil humic acids, which are commonly used in small doses and with high frequency (3÷6 treatments) [55]. Lichner et al. (2012) studied the impact of biological soil crust consisting of three species of algae: *Choricystis minor*, *Klebsormidium subtile* and *Tribonema minus* on the hydrophysical parameters of sandy soil. Higher water repellence, water holding capacity, hydraulic conductivity of the soil was observed when compared to the control soil. Additionally, biological soil crust influences on the increase of soil organic carbon and increase of water drop penetration time [56]. In a study of Haslam and Hopkins (1996) it was shown that the use of alga *Laminaria digitata* (cut into small pieces) caused an increase in: pore volume, aggregate stability, biomass of soil microorganisms and biological activity of sandy soil (respiration and nitrogen mineralization) [57]. Caiozzi et al. (1968) investigated the effect of seaweed on the level of phosphorus and nitrogen in calcareous soils, compared with KNO_3 and KH_2PO_4. After 21 days, an increase in phosphorus content in the soil with addition of seaweeds was observed in contrast to the soil with the addition of KH_2PO_4. This may suggest that the available phosphorus in algal biomass occurs in a different chemical state than in inorganic compounds. The form of occurrence could cause that plants less absorb it or soil microorganisms immobilize it worse. It is possible that the phosphorus present in algae forms compounds, which are hardly biodegradable by microorganisms. These compounds form soluble complexes with the major soil elements (Ca, Fe, Al), thus preventing the binding of P(V) by the soil. Decrease in nitrogen content was probably caused by the transformation to organic form by microorganisms. The phenomenon of nitrogen immobilization is supported by the presence in the soil material with a low nitrogen content, such as algae [58].

The influence of algae on plants

Algae as physioactivators

Long–term cooperation of the Goëmar company with the French research institutes (e.g. INRA – National Institute for Agricultural Research, Universities of Rennes, Bordeaux and Marseille), confirmed the positive effects of *Ascophyllum nodosum* extract on growth and yield of plants. This group of products was described as **physioactivators** based on the PAT technology (Physio Activator™ Technology), because they stimulate plant growth and development. The mechanism of the action of physioactivators relies on their parallel effects on several processes: activation of plant mineral nutrition through stimulation of enzymes that play a key role in the uptake of nutrients and enzymes (such as: nitrate reductase and phosphatases); activation of photosynthesis by increasing the activity of chlorophyll and its contents in leaves; activation of the increase of the biomass of plants (both aboveground part and root system) and as an effect improved mineral nutrition (including: N, P, K, Mg, Mn and Fe), and increased efficiency of photosynthesis; the activation of flowering and fruit setting by stimulating the synthesis of polyamines – compounds responsible for abundant flowering, pollination efficiency and fruit set. Higher levels of polyamines stimulate the intensity of cell division, leading to an increase in their numbers [59]. The algal active ingredients may stimulate nitrate reductase and other plant enzymes responsible for absorbing minerals and their transformation in the plant, and thus they act as physioactivators. The immediate effect of their actions can be changing the chemical composition of plants [60].

Algae as biostimulants

Conditions for growth of plant and thus the yield can be improved through the use of various natural additives, which enrich the soil. They are manufactured on the basis of natural substances found in biological materials, such as algae, which have very strong biostimulating properties [51]. Biostimulants from algae are used primarily after germination the plants, in the form of successive spraying, although the use directly to the soil is not excluded and can also produce positive results [61]. Some natural biostimulants are listed in the "List of fertilizers and soil conditioners qualified for use in ecological farming", approved by the Institute of Soil Science and Plant Cultivation in Puławy [62]. It includes **AlgaminoPlant** (15% extract of marine algae *Sargassum* and 10% α-amino acids).

Examples of studies conducted on plants with the use of algal extracts

In a study conducted by Dobrzański et al. (2008) it was shown that the conditioning of carrot seeds and parsley in a 0.5% solution of biostimulant **AlgaminoPlant** improved germination. There was also a tendency to increase the marketable yield of carrot roots and to increase the share of marketable yield in total yield due to application of fourfold after sowing, and soon after the emergence of carrots at intervals of 7–14 days (1dm^3/ha in each treatment). The tendency to reduction of nitrates and to increase the content of carotenoids was pointed out [61]. Kumar and Sahoo (2011) studied the effect of the extract prepared from the alga *Sargassum wightii* on the growth and yield of wheat (*Triticum aestivum*) using different concentrations of extracts: 5, 10, 20, 30, 40, 50 and 100%. The best results were obtained for the concentration of 20% and for 100% the worst. A beneficial effect of algal extract on the germination, root length, shoot length, number of branches, length of grain and dry seed weight was observed [63]. The results obtained by Matysiak et al. (2010) indicated on a stimulating effect of marine algae (products: **Kelpak SL** – *Ecklonia maxima* and **AlgaminoPlant** – *Sargassum* spp.) on the germination of oilseed rape. Lower dose of algal extracts showed better performance, as compared to higher doses: for product Kelpak optimal dose was 1.5 cm^3/200 cm^3 H_2O, for product AlgaminoPlant – 0.5 cm^3/200 cm^3 H_2O [64]. Literature reports that algal extracts (*Ulva* sp. (35%), *Codium* spp. (18%) and *Dictyota* sp. (17%)) produced through composting, were tested in the assessment of growth rate of tomatoes, which were grown on different kind of soils: sand, sandy-loam soil and sandy-loam soil with inorganic fertilizers, to which different doses of algal compost were added. The results showed that in all cases the addition of compost increased the maximum capacity of water and plant growth. Growth of tomato (*Licopersicum esculentum var. Platense*) was proportional to the dose of compost [65]. Rathore et al. (2009) studied the effect of foliar application of various concentrations of algal extract: 0, 2.5, 5, 7.5, 10, 12.5 and 15% v/v (prepared from *Kappaphycus alvarezii*) on nutrient uptake, growth and yield of soybean (*Glycine max* (L.) Merr.). Crops were conducted without the use of fertilizers. The best results were obtained when using 15% algal extract, for which the soybean yield was 57% greater than in the control group [66].

Algae in plant protection

In modern agriculture, a wide variety of chemicals is used in order to control diseases and pests. In this way, very often a big losses are prevented and on the other hand it allows for obtaining higher–quality crops. However, in ecological farming, only products based on natural substances (such as plant extracts) should be used. Their action is not as immediate, but it poses less risk to the environment. Once, in the fight against diseases and pests, extracts from plants such as: horsetail, nettle, garlic, dandelion, chamomile etc. were used [50]. Today, for the preparation of products, which will stimulate the immunity against pathogens, seaweeds can be used. One of these preparations is biostimulant **Vacciplant** available in several countries in European Union and in the United States. It is produced on the basis of *Laminaria digitata*. It stimulates defence mechanisms of plants, acting as a "vaccine", which protects the plant against diseases. During the attack, the pathogen produces substances that damage cell walls of plants (e.g., oligoglucans). All harmful substances produced by fungi during the attack are named – elicitors, which are the stress factors that stimulate plant defence response. Plant response to pathogen attack and activity of elicitors is the production of cells a signal to the defence, e.g., lignifications of cell walls and the production of compounds toxic to the pathogen (e.g., phytoalexins, phenolic compounds). Vacciplant thus acts as elicitor, which pretends the action of the substance produced during pathogen attack [59].

In the work of Horoszkiewicz–Janka and Jajor (2006) the effect of seed dressing on the healthiness of barley, wheat and rape in the early development stages was investigated. One of the tested products was **Kelpak**, which is extracted from marine algae *Ecklonia maxima*, collected from the coast of South Africa. This product stimulates plant growth and improves the quantity and quality of yield. The positive effect of this growth regulator is widely used in the cultivation of vines and citrus fruit, agricultural crops and ornamental plants. It was shown that the dressing of spring rape with Kelpak, caused a reduction in the percentage of infected plants by about 50% [67]. A similar biopreparation is **Bioalgeen S 90 Plus 2**, which is also extracted from marine algae. Its application promotes the expansion of the root system, greater resistance to stress and increase resistance to the pathogens attack. Better-developed root system improves the tolerance to stress caused by disease-causing pathogens and pests, increases yields and improves their quality [68]. In a study conducted by Horoszkiewicz–Janka and Michalski (2006) the effect of foliar application of biostimulator: **Bioalgeen S 90 Plus 2** on the quality and the presence of microflora in the grain of spring barley, husked and naked oats was defined. It was shown that the application of this preparation reduced the pathogenic fungi in grain of all tested species [68]. Sultana et al. (2005) showed that the use of algae: brown: *Stokeyia indica*, *Padina pavonia* and red: *Solieria robusta* as agents, which improve soil properties, had a positive effect on the reduction of root infection of okra (*Abelmoschus esculentus* (L.) Moench.) caused by pathogens: *Macrophomina phaseolina*, *Rhizoctonia solani* and *Fusarium solani* [69]. Also in the work of Ehteshamul-Haque et al. (1996) it was shown that brown algae: *Stoechospermum marginatum* and *Sargassum tenerrimum*, used as organic amendments under greenhouse conditions, significantly reduced the population of *Meloidogyne javanica* and fungi that cause infections of the root [70]. The literature also shows that red alga: *Solieria robusta* acts better against rot the roots of soybean (*Glycine max* (L.) Merrill.) caused by *Fusarium solani* than the fungicide – Topsin–M [71].

The potential application of algae

Sustainable agriculture is conducting agricultural production by environmentally friendly methods. Also algae production could be more environmentally friendly and efficient by closing production cycles, where animal wastes are used as a medium for the growth of microalgae. In this way, nutrients not used by the animal organism can be used to increase the biomass of microalgae, which can then be added to animal feed, as a natural biomass or biomass enriched with microelements [72, 73]. By introducing additional link – algae to the chain of production in agriculture, will be possible to obtain a closed cycle in which the waste from one process play role of substrates for the next one, creating a nearly self-sufficient farm. Algae ponds fed with animal waste serve as the oxidation ponds. Algae bind free nutrients into the biomass, and in this way purify water, produce oxygen, which is essential for growth of aerobic bacteria and other aquatic organisms. If the fish are breeding in those ponds, the algae provide food and create the optimal environment for fish farming. Microalgae are responsible for the biological transformation of solar energy and nutrients from the waste to the biomass of microalgae, which can undergo anaerobic fermentation giving methane (approximately 60%) and of CO_2 (about 40%), which in turn can be returned to cultivation of microalgae as a source of carbon. Literature also presents new opportunities for the use of algae in the animal nutrition. Comparing the content of microelements in conventional feed with the composition of microalgae biomass, it appears that the content of microelements in the biomass of algae after the enrichment is much higher than in barley, corn, oats, wheat, rye, potatoes and fodder yeast [19, 74]. The role of algae in modern agriculture is presented in Figure 2.

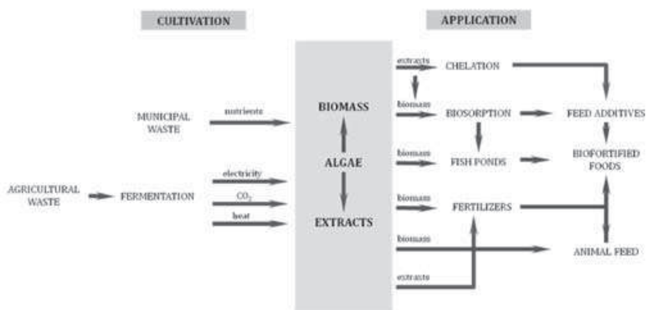

Fig. 2. The role of algae in modern agriculture

Literature describes attempts to enhance the biomass of *Spirulina platensis* in selenium and iodine [75, 76], which resulted in the receipt of pharmaceuticals, which can be used as human dietary supplements. Such formulations provide the ingredients, in more digestible form. Trend enrichment of organisms with good nutrition through biosorption and bioaccumulation is a fact which is confirmed by literature reports for example copper-enriched yeast that have solved the problem of micronutrient deficiency in the diet of humans and animals [77].

Summary

The present study describes the algae (micro- and macroalgae) as a new raw material for agriculture. That potential has not yet been fully exploited, yet.

Algae are a challenge for sustainable agriculture, known from the valuable nutrients, and used as dietary supplements. In modern agriculture can be used in animal nutrition as well as carriers of trace elements in soil fertilization. In addition, it is proposed to apply the process of biosorption as a method of binding metal ions to biomass. The introduction of mineral additives by the produced algal biomass enriched by biosorption will reduce the uncontrolled accumulation of trace elements in the environment.

It is also possible to use minerals excreted in the faeces of livestock in integrated farms where farm wastes could be used as a medium for the cultivation of microalgae.

Acknowledgements

The work was supported by Polish Ministry of Science and Higher Education – project No N R05 0014 10.

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Translation into English by the Author

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