AGRICULTURAL BIOLOGY,
2023, V. 58, Iss. 6, pp. 1006-1020
[SEL'SKOKHOZYAISTVENNAYA BIOLOGIYA]

ISSN 2412-0324 (English ed. Online)
ISSN 0131-6397 (Russian ed. Print)
ISSN 2313-4836 (Russian ed. Online)

UDC 636.085

doi: 10.15389/agrobiology.2023.6.1006eng
doi: 10.15389/agrobiology.2023.6.1006rus

MARINE ALGAE: EVALUATION OF THE POTENTIAL FOR USE IN FARM ANIMAL DIETS
(review)

I.I. KOCHISH, E.E. ZIMIN, I.N. NIKONOV✉

Skryabin Moscow State Academy of Veterinary Medicine and Biotechnology, 23, ul. Akademika Skryabina, Moscow, 109472 Russia, e-mail kochich.i@mail.ru, eug2.zimin@gmail.com, ilnikonov@mgavm.ru (✉ corresponding author)
ORCID:
Kochish I.I. orcid.org/0000-0002-8502-6052
Nikonov I.N. orcid.org/0000-0001-9495-0178
Zimin E.E. orcid.org/0009-0007-9244-7334
The authors declare no conflict of interests
Acknowledgements:
Supported financially by a grant from the Russian Science Foundation (project No. 22-16-00009)
Final revision received April 04, 2023
Accepted April 22, 2023

Abstract

Currently, in the feed industry, along with energy-saving progressive technologies, non-traditional raw materials and secondary products of food industry are widely used. Processing and use of non-traditional resources at food enterprises significantly increases their profitability and reduces grain costs in compound feeds (P. Burtin, 2003). Natural components provide high-quality feeding for animals, strengthen their health and improve production performance. Currently, studies of the biological activity of algae phlorotanins are still relevant. The variety of biological properties determines their practical use, including in the production of feed additives for animals (S.B. Wang et al., 2013). An important problem is the uncontrolled use of antibacterial drugs, which can lead to the transfer of antibiotic resistance from animal to human (I.I. Kochish et al., 2019). Probiotics, prebiotics, symbiotics, organic acids, etc., serve as an alternative to feed antibiotics. These supplements are not inferior to antibiotics in effectiveness, but exclude their negative effects (I.A. Egorov et al., 2019). Seaweeds have a prebiotic effect due to the oligo- and polysaccharides and antimicrobial, immunomodulatory, antioxidant and anti-inflammatory activity due to bioactive compounds. Depending on the purpose of application and with the optimal dosage, seaweeds can positively affect animal ontogenesis, productivity and the quality of the products obtained. In poultry farming, seaweeds strengthen the immune state, reduce the microbial load in the digestive tract and improve product quality (A.M. Abudabos et al., 2012). Green algae (*Entermorpha prolifera*) contribute to better digestibility of nutrients, increase the level of metabolized energy, lead to higher egg production and a better egg quality (an increase in weight, shell thickness, change in yolk color), as well as reduce the yolk cholesterol level (S.B. Wang et al., 2013). Dried, boiled and autoclaved brown algae (*Sargassum dentifebium*, *Turbinaria conoides*, *Dictyota dentata*, etc.) in the diet of young chickens and laying hens have no adverse effects on productivity performance and feed intake while positively influence yolk coloration and the calcium content in the shell. Dietary brown algae *Sargassum* sp. reduces levels of cholesterol and triglycerides in blood and yolk in laying hens with an increase in the yolk carotene, lutein and zeaxanthin concentrations (M.A. Al-Harthi et al., 2012). Red algae (*Asparagopsis taxiformis*) in the diet of animals can positively change the microbiome of the gastrointestinal tract, increasing the diversity and abundance of beneficial bacteria (B.M. Roque et al., 2019). Thus, due to its special biochemical composition, seaweeds is promising in feeding highly productive crosses of poultry, pigs and cattle.

Keywords: algae, antibiotic resistance, intestinal microflora, immunity, probiotics, prebiotics, *Campylobacter*, polysaccharides, biochemical analysis, feed additive

Currently, in the feed industry, along with the energy-saving advanced technologies, non-traditional raw materials and secondary food production resources have become widespread, reaching 60-80%, in some cases 95%, by weight of feed. Processing of secondary resources at food enterprises significantly increases their profitability and reduces the cost for grain in the commercial compound feed [1].

In 2050, due to continued population growth and climate change, 60-70% more animal products will be needed than currently consumed [2]. Livestock production will require more feed, which will be a significant challenge given land degradation due to past intensification methods and weather conditions [3]. Expanding the feed supply through new resources or additives that improve feed efficiency can play a key role in the development of animal farming [4].

Natural feed resources are one of the most effective ways to improve animal nutrition, health, functional performance and productivity [5].

Algae which contain large amounts of bioactives and nutrients are underutilized as a crop [6-8]). In vivo studies in ruminants, pigs, poultry and rabbits show that some seaweeds can meet protein and energy requirements, while others contain bioactive compounds that enhance animal performance and health [9]. In seaweed, the protein yield per unit area is 2.5-7.5 $t \cdot ha^{-1} \cdot year^{-1}$, for soybeans, legumes, wheat 0.6-1.2, 1-2 and 1.1 $t \cdot ha^{-1} \cdot year^{-1}$, respectively. It is also worth noting that freshwater conditions and arable land are not required to grow algae [10].

The second important problem in livestock farming is the uncontrolled use of antibiotics. Along with bacteriostatic and bactericidal effects against most gram-positive and gram-negative bacteria, antibiotics have undesirable side effects, the microbiota of the gastrointestinal tract (GIT) is inhibited, immunity is weakened, and pathogens mutate and develop resistance [11]. Uncontrolled use of antibacterial drugs can lead to the transfer of antibiotic resistance from animals to humans [12], which was the reason for the ban of most of them in the United States and Western Europe [13].

Drugs that serve as an alternative to feed antibiotics include probiotics, prebiotics, symbiotics, and organic acids [14]. These additives are not inferior to antibiotics but exclude these negative effects [8]. Mariculture products, namely seaweed is such raw materials. They contain substances, many of which are absent in terrestrial organisms, and have increased biological activity [15, 16].

In this review, we summarized published data on the properties of micro- and macroalgae that determine their potential as feed resources and/or additives for farm animals and poultry, and examined practical examples.

All algae are divided into 10 sections. Of these, brown algae (*Phaeophyta*), blue-green algae (*Cyanophyta*), and red algae (*Rhodophyta*) are the main [17, 18]. Over the millions of years of our planet's history, macrophyte algae acquired perfect morphological and physiological features and adapted to changing environment, which led to their wide distribution and diverse biotic relationships with other species [19-21].

Algal fields and marine plantations have high biological productivity [21-23]. Algae fields dampen sea wave energy, limiting destructive impact on the coastline during storms [24]. Algae serve as an additional substrate on which eggs and larvae of aquatic organisms settle, and as a refuge from predators for the young of many animals [25-27]. A favorable hydrological and hydrochemical regime is created in algal rhizoids and between the plates, promoting the development of microalgae, the accumulation of detritus and the formation of a microbial film [28, 29]. Algae are biological filters for purifying polluted coastal waters near large cities. Macrophyte populations in wastewater discharge sites reach their fullest development due to nutrition improved with additional sources of nitrogen and phosphorus [30-32]. A 1 ha kelp plantation is capable of extracting about 250 kg of nitrogen from water per day. Seaweed produces a significant proportion of the world's oxygen, 80% of oxygen is produced by macrophyte seaweeds and microalgae, and only 20% by terrestrial plants [33, 34].

Macro- and microalgae. *Macroalgae.* Macroalgae are brown (*Phaeophyceae*), red (*Rhodophyceae*) and green algae (*Chlorophyceae*) [35].

Brown algae primarily live in shallow waters or on coastal rocks and have flexible stems that allow them to withstand seewaves. Because of large size and ease of collection, brown algae are the most studied and more commonly used in animal nutrition than other types of algae. The most common genera are *Ascophyllum*, *Laminaria*, *Saccharina*, *Macrocystis*, *Nereocystis*, and *Sargassum* [35-38].

Red algae have a characteristic bright pink color caused by the pigments R-phycocyanin and R-phycoerythrin. Most marine red algae are found at depths of up to 100 m. The main genera of red algae are *Pyropia*, *Porphyra*, *Chondrus* and *Palmaria*. Dead coralline red algae, especially *Phymatolithon* and *Lithothamnion*, form calcareous deposits that are used throughout the world for calcium carbonate.

The color of green algae is due to chlorophyll in the chloroplasts. Color may vary depending on pigment balance. The main genera of green algae are *Ulva*, *Codium*, *Enteromorpha*, *Chaetomorpha* and *Cladophora*. These algae are common in well-lit areas in shallow waters (39).

The chemical composition of seaweed is variable and depends on the species, time of collection (season of the year), habitat, and external conditions, e.g., water temperature, light, concentration of nutrients in water, etc. [16, 40]. Seaweeds are characterized by a high content of macro- and microelements, that is, the concentrations may exceed those in terrestrial plants [36]. The high mineral content is due to absorption of inorganic substances from the environment. Algae also contain polysaccharides and small amounts of fats, which are mainly polyunsaturated fatty acids. C. Corino et al. [41] point out the high content of vitamins A, B_1, B_{12}, C, D, E, B_2, B_3, B_5, B_9 in algae.

Among marine organisms, algae are one of the richest sources of natural antioxidants and antimicrobial substances [42]. Due to the significant water content (70-90%), seaweed must be dried or sold quickly due to the risk of mold. To produce seaweed meal, wet seaweed is passed through hammer mills with sieves of decreasing size. Then seaweed mass is dried in a drum dryer at 700 to 800 °C and finally at 70 °C to 15% humidity and stored in sealed containers [4]. Uncontrolled use of dietary algae can negatively affect animal performance [43].

Microalgae. Of the 30,000 species of microalgae thought to exist, only a few are used and grown commercially. The most biotechnologically important microalgae are green algae *Chlorella vulgaris*, *Haematococcus pluvialis*, *Dunaliella salina* and the cyanobacterium *Spirulina maxima*. According to model calculations based on the cultivation of microalgae in open pools and experimental installations, the annual biomass yield is 15 t DM/ha. In phytobioreactors production can be doubled. These differences also depend on climate and the rate of photosynthesis.

Composition of microalgae depends on the nutrient medium, time of year, light intensity, and temperature. Bioreactors ensure regulation of culture regimes and, thereof, the composition. Vitamin content depends on environmental conditions, post-harvest processing and drying method. Microalgae are 7-14% ash and approximately 5% nucleic acids which also depends on the culture conditions. As with macroalgae, it is always worth paying attention to accumulation of heavy metals [44]. The Table indicates the main chemical components of some maro- and microalgae.

Approximate chemical composition of some macro- and microalgae [38, 44]

Name	Content, % dry matter		
	crude protein	carbohydrates	crude fat
	Macroalgae		
Ulvalactuca	10-25	36-43	0.6-1.6
Chondrus crispus	11-21	55-68	1.0-3.0
Laminaria digitata	8-15	48	1.0

Continued Table

	Microalgae		
Spirogyra sp.	6-20	33-64	11-21
Chlorella vulgaris	51-58	12-16	14-22
Arthrospira maxima (*Spirulina*)	60-71	13-16	6-7

Algae in poultry farming. According to many reports, 1-5% seaweed added to feed can be used in poultry farming to improve the immune status, reduce the microbial load in the digestive tract and improve the quality of the resulting product [45-47].

Calcined red seaweed is a valuable source of organic calcium for broilers due to greater availability compared to inorganic limestone. Red seaweed improved the poultry's skeletal system, reducing limb weakness and lameness [48].

Green algae *Entermorpha prolifera* fed at 2-4% of the total diet promote better utilization of nutrients and energy metabolization in broilers, which may be due to an increase in amylase content in the duodenum. There was a positive effect on feed intake, feed conversion ratio and average daily gain, with a decrease in abdominal and subcutaneous fat thickness and, therefore, improved breast quality [46].

Adding 1-3% dietary *E. plifera* improves the egg production and quality in chicken, egg weight, shell thickness and the yolk color intensity increase, and yolk cholesterol decreases. In addition, the abundance of *Escherichia coli* in feces decreased, which could indicate improved bird health. The feed conversion ratio also improves [47].

M.A. Al-Harthi et al. [49, 50] reported that up to 6% of dried, boiled and autoclaved brown algae *Sargassum dentifebium* can be added to the diet of young poultry and laying hens from week 14 to week 42 without a negative effect on productivity and feed consumption. The yolk color improved by 12.31% and the shell calcium content by 9.1% compared to the control.

M.A. Al-Harthi et al. [51] also recommend up to 6% of the brown alga *Sargassum* sp. in the diet of laying hens aged from 23 to 42 weeks to reduce the content of cholesterol and triglycerides in the blood and yolk. In addition, the amount of carotene, lutein and zeaxanthin increased, as well as yolk palmitic acid [51].

AS per A.A. El-Deek et al. [52], laying hens fed S. *dentifebium* at 1 g/kg diet in combination with green tea (1 g/kg) or vitamin E (300 mg/kg) increased productivity with better egg quality under heat stress (32±4 °C). According to M.A. AI-Harthi [49], brown algae increased egg production by 1.2% and improved feed conversion by 5.2% compared to control. When using vitamin E, egg shell was 6.6% thicker, and brown algae together with vitamin E increased the yolk color intensity by 9.1% and decreased the cholesterol content in fresh eggs by 16%.

Replacing 3% corn in the diets of broiler chickens aged 12 to 33 days with green algae *Ulva lactuca* contributed to an increase in breast muscle mass by 2.3%, a decrease in the blood concentrations of total lipids by 125.1 g/100 ml, cholesterol by 29.5 g/100 ml, and uric acid by 2.68 g/100 ml [47].

In order to find an alternative to antibiotics, G. Kulshreshtha et al. [53] tested the red algae *Chondrus crispus* and *Sarcodiotheca gaudichaudii* on 67-day-old Lohmann Brown Classic laying hens. In the intestines of birds fed 2% dietary red algae the population of beneficial bacteria *Bifidobacterium longum*, *Streptococcus salivarius* and the number of *Clostridium perfringerns* increased. There was also an increase in the concentration of short-chain fatty acids, including acetic, propionic, butyric and isobutyric acids. The authors note that the chickens had a larger villi surface area and crypt depth. When fed 1% red algae, the weight of the yolk and eggs increased [53]. In further research, it was suggested that the previously obtained results [53] are associated with the content of biologically active compounds in algae, such as agars, carrageenans, xylans, sulfated galactins and porphyrins [54, 55].

According to Y.A. Mariey et al. [56], laying hens fed 0.2% spirulina had better feed conversion (4.54 vs. 3.46) and produced more eggs (52.3 vs. 63.3%), additionally, the egg weight increased (48.5 vs. 51.82 g) compared to the control. The microalgae increased the percentage of yolk to albumen. Due to the supplement, the cholesterol concentration decreased in the yolk (13.5 vs. 10.2 mg) and in the blood (116.25 vs. 108.91 mg/100 ml). The percentage of fertilized eggs (90.87 vs. 96.58%) and hatchability (89.81 vs. 95.75%) were higher in the chickens fed a spirulina supplement [56].

In a study of the antimicrobial properties of six red seaweed extracts against *Salmonella enteridis* using a the nematode *Caenorhabditis elegans* model of infection, only two species of macroalgae, the *Sarcodiotheca gaudichaudii* and *Chondrus crispus* had the necessary properties. Aqueous extracts of algae, from 0.4 to 2 mg/ml, significantly reduced the growth and mobility of Salmonella enteritidis and reduced the formation of biofilms. RT-PCR results showed that the extract suppressed the expression of the *sdiA* gene (quorum sensing) and the pathogenicity island (island-1) genes *sipA* and *invF* in *S. enteridis*. It was hypothesized that the algae extract could reduce the *S. enteritidis* invasion in the host by attenuating virulence factors. In addition, aqueous extracts significantly improved the survival of infected *C. elegans* by interfering with the ability of *S. enteridis* to colonize the digestive tract of nematodes and increasing the expression of *C. elegans* immune genes (*irg-1*, *irg-2*, *hsf-1*). The authors suggest that extracts may also have beneficial effects on animal and human health [54, 57].

M.L. Manor et al. [58], studying the effect of the microalgae *Nannochloropsis oceanica* on laying hens of the Shaver-White Leghorn cross, revealed an increase in the concentration of ω-3-docosahexaenoic acid in eggs, liver and muscles, which correlated with the activation of key genes for elongation (*ELOVL3*, *EKIVL4*, *ELOVL5*) and desaturation (*FADS5*, *FADS6*) of polyunsaturated fatty acids. The authors point out the need for further research to confirm their findings.

When 3-day-old chicks were infected with *Campylobacter jejuni*, it was found that laminarin or laminarin/fucoidan extracts from the brown algae *Laminaria digitata* improved feed intake, increased the expression of key genes involved in the immune response (*IL-6*, *IL-8*), and promoted an increase in villus height in the small intestine and the growth rate of chickens. Laminarin extract was effective in increasing villous height and *TLR-4* gene expression compared to the control and laminarin/fucoidan extract groups. However, these supplements did not affect *C. jejuni* colonization [59].

Algae in cattle breeding. Macroalgae, when < 2% added to cattle diets, are capable of powerful prebiotic activity, 5.5 times greater than prebiotics from fructooligosaccharide (FOS) or inulin. As a result, the pathogenic load is reduced, the condition of the gastrointestinal tract is improved, productivity increases, the immune system is strengthened, and the animals' resistance to stress increases. Positive changes in the composition of the gastrointestinal tract microbiota resulted in increased digestibility of the entire diet and a reduction in methane emissions [43]. P.S. Erickson et al. [60] state that the use of algae supplements has been practiced for quite some time on organic dairy farms in the United States.

Research into the causes of *E. coli* infection in cattle has identified feces as an important source of reinfection. The drug Tasco (Acadian Seaplants, Ltd., Canada) based on *Ascophyllum nodosum*, used at a dose of 20 g/kg of diet for 7 days, effectively reduced the duration and intensity of *E. coli* O157:H7 excretion in feces in bulls. The results obtained were confirmed in the second experiment when feeding the supplement to lambs at a dose of 10 g/kg for 28 days [61]). C.C. Lopez et al. [62] in a study on lactating cows proved that the use of *A. nodosum* in mixed feed, 100 g/kg, increased the milk iodine content compared to the control, up to 1.96 mg/l vs. 0.92 mg/l. In addition, the supplement increased the abundance of the gram-positive bacterium *Lactococcus lactis*, which is essential in cheese production [62].

Microalgae can stimulate the growth of microorganisms in the gastrointestinal tract of cattle. Supplements containing probiotic microorganisms do not lead to persistent microflora colonization. A.V. Konovalov et al. [63] found that a chlorella suspension (500 ml) increases the average daily gain in bodyweight of young cattle by 89 g and helps reduce the period of adaptation to changes in diet at 3 months of age [63]. According to C.N. Garces et al. [64], the spirulina microalgae fed to Montbéliard cattle 21 days before calving (15 and 30 g/day) did not affect bodyweight, productivity performance or the somatic cells counts in milk. In colostrum, the highest IgG content (75.6 g/l) was observed at a spirulina dose of 15 g/day. The lactose content in milk turned out to be the highest (5.6 vs. 5.5% in the control) at 30 g fed per day [64].

According to V.V. Petryakov [65], the amount of spirulina optimal for increasing the protective function of cattle is 400 ml/day. In a study on red-motley Holstein cows, he found that feeding spirulina increased natural resistance, e,g., blood bactericidal activity by 8.5%, lysozyme activity by 6.5%, phagocytic activity of neutrophils by 2.1%.

According to E.A. Tretyakov et al. [66], feeding black-and-white heifers with a chlorella suspension (500 g/day) during milk feeding contributed to an increase in feeding activity and average daily gain. A positive effect of spirulina on the rumen microflora in young animals was revealed. No differences were observed between the groups in physiological parameters. In the experimental group, the content of total blood protein increased by 6.7%, gamma globulins by 28% (vs. 25.47% in the control). Other indicators remained within normal limits.

Red algae *Asparagopsis taxiformis* in an amount of 5% of dairy cattle diet can reduce methane emissions. 16S rRNA gene amplicon sequencing showed that algae influence the composition of the rumen microbiome. In fermentation vessels under in vitro conditions, the relative content of methanogens decreased significantly compared to the control. A rapid effect of *A. taxiformis* on the metabolic activity of rumen methanogens was revealed, while the effect on the microbiome composition (e.g., a prevalence of methanogens) was delayed [67].

Algae in pig farming. The prebiotic effect and antimicrobial activity of laminarin and fucoidan may be useful for the preventive treatment of gastrointestinal diseases and increasing the digestibility of the diet in piglets after weaning. Laminarin supplementation (600 mg/kg) significantly increases the expression of mucin genes (*MUC 2* and *MUC 4*), exerting a protective effect on epithelial cells. Anti-inflammatory effects and a decrease in cytokine response occurred at a dose of 1 mg/ml. An immunomodulatory effect was achieved using seaweed extract (1.8 g/day) in pregnant sows. Increased production of immunoglobulins A and G in pigs was observed for a 0.8% extract [68].

Alginic acid oligosaccharide is a natural polysaccharide isolated from the cell walls of seaweeds. The addition of an oligosaccharide in an amount of 100 mg to the diet of weaned piglets increased the average daily weight gain, antioxidant activity, and the blood concentrations of IL-10, IgG and IgA. The content of secretory immunoglobulin A, the height of the villi and the activity of disaccharidase (lactase and sucrase) in the small intestine increased. The population of bacteria, including *E. coli*, decreased, and the abundance of *Bifidobacterium* and *Lactobacillus* increased [69].

C. Corino et al. [41] summarized reports on using algae in pig diets. They paid particular attention to brown seaweed, emphasizing its effect on the immune system, gut health and antioxidant status of animals. The use of brown algae in the diets of weaned piglets is recommended for the prevention of gastrointestinal diseases. An increase in the production of immunoglobulin and cytokines has been noted [41].

It was established [70] that the brown seaweed *Ecklonia cava* at 0.15% of the diet increased average daily weight gain of weaned piglets and changed the intestinal microflora, the number of *Lactobacillus* spp. increased by 0.26%, while *E. coli* spp. and *Clostridium* spp. decreased by 0.26% and 0.22%, respectively. The supplement had no effect on villous development in the small intestine [70].

M. Dell'Anno et al. [71] assessed the antioxidant and antimicrobial capacity of the brown alga *A. nodosum* and the microalga *Schizochytrium* sp. against the intestinal pathogen *E. coli* O138 in vitro using the broth macrodilution method. It turned out that *A. nodosum* is able to modulate the growth of *E. coli* for a short time, and *Schizochytrium* sp. has antioxidant capacity, which can be enhanced due to a synergistic effect. Given the urgent need for innovative functional feed additives, these algae can be used as an alternative to antibiotics [71].

Seaweed powder in sow diets (30 g/day) from 85 days of pregnancy to the end of lactation improved the immune status of piglets. Based on the analysis of T-lymphocyte subsets in 40-day-old piglets, an increase in the population of CD4+ CD8+ T-cells was noted in the thymus, lymph nodes, tonsils, peripheral blood mononuclear cells, spleen and liver [72].

Spirulina platensis at 2 and 3 g/day in pig diets led to an average daily increase in live weight by 14.3% and an improvement in feed conversion by 6.1%. There was a slight effect on hematopoiesis (15 and 13% more red blood cells and hemoglobin), and there was also a tendency to reduce morbidity by 59% [73].

P. McDonnel et al. [74] suggest that laminarin may improve the intestinal health of piglets after weaning. The authors recorded a decreased counts of *E. coli* in feces and noted an increase in the average daily weight gain. The co-use of laminarin and fucoidan (a sulfated polysaccharide) after weaning can reduce the incidence of diarrhea in piglets [74]. N. Derek et al. [75] in an experiment on piglets revealed an improvement in intestinal microflora and lower *E. coli* counts. The effect was presumably due to bioactive compounds alginates, fucoidans, laminarins, phloratannins of the *A. nodosum* supplement [75].

In order to strengthen the immune system and further replace antibiotics in pig farming, M. Katayama et al. [76] recommend using seaweed (0.8%) and licorice (0.15%). The authors note an increase in the amount of IgA in the mucous membrane and blood IgG. The supplement complex was shown to enhance the anti-inflammatory effect. i.e., interleukin gene expression was detected [76].

Biologically active substances of algae against campylobacter. Lack of sensitivity to antibiotics in bacteria is one of the most important risk factors for human health, since it reduces the effectiveness of drugs used to treat diseases. This also leads to an increase in the frequency of transfer of genes encoding resistance to other microorganisms, as a result of which new pathogens with increased aggressiveness appear in the environment. According to the World Health Organization (WHO), resistance of bacteria, mainly zoonotic pathogens, to antibiotic drugs currently poses one of the greatest threats to humanity [77]. The World Organization for Animal Health, concerned about the rapid development and spread of antibiotic resistance among animal pathogens, has developed recommendations for veterinary services [78].

The active use of antibiotics as growth stimulants in animal feeding plays an important role in the emergence and spread of resistant bacteria [79]. The intensification of agriculture, expanded range of disinfectants and antiseptics, and the uncontrolled use of antibiotics in livestock farming increasingly select food-borne pathogens that are antibiotic resistant. The most epidemiologically significant are gram-negative bacteria of the *Enterobacteriaceae* family and the genus *Campylobacter*. The main transmission factors for campylobacteriosis are poultry and poultry derived products [80]. Campylobacteriosis monitoring in Europe officially estimates approximately 200,000 cases per year [81, 82]. The causative agents of intestinal campylobacteriosis include thermophilic bacteria of the genus *Campylobacter*, species *C. jejuni*, *C. coli, C. lari*, *C. upsaliensis* and *C. helveticus* [83, 84].

To prevent and treat campylobacteriosis in poultry, it is necessary to increase the number of beneficial bifidobacteria and lactobacilli and to reduce stresses from changing diets and vaccinations in traditional regimens for the use of veterinary drugs [85].

Algae contain two important groups of substances that have a wide range of biological activities. The first group is fucoidans, which are characterized by antibacterial, antiviral, anticoagulant, immunomodulatory, anti-inflammatory, and antitumor activity [86, 89]. Another most important compounds are polyphenols, namely phlorotannins, the polymers of phloroglucinol. The content of phloroglucinol varies depending on the type of brown algae and the place where they grow, reaching 20% DM [34]. Phlorotannins have been described as antioxidant with activity 2-10 times higher than in ascorbic acid and α-tocopherol [90], antiviral [91], antitumor [92], neuroprotective [93], antithrombotic [94], antimicrobial [95], and antiallergic [96]) properties.

Various formulations containing fucoidans as bioactive components are being developed for medical use, such as dressings [87]. The lack of toxicity along with bacteriostatic properties allows their use in the food industry, increasing the shelf life of products and not suppressing beneficial microflora [88].

Thus, the marine environment is a promising source of bioactive compounds that are currently underutilized in commercial animal farming. The variety of biological properties of algae determines their various practical use, including production of feed additives for pig farming, poultry farming, and cattle breeding. Algae exhibit not only a prebiotic effect due to the oligo- and polysaccharides they contain, but also antimicrobial, immunomodulatory, antioxidant and anti-inflammatory properties due to bioactive compounds. Depending on the purpose of use and subject to the optimal dosage, algae can have a positive effect on ontogeny, animal performance and the quality of the resulting product. Algae can also module the composition of microbial communities in a positive way, suppressing pathogenic microorganisms. Reducing the risk of infectious diseases is due to healthy microbiota, which can provide high resistance to intestinal colonization by pathogens. The condition of the intestines determines the health of the animal, the efficiency of utilizing nutrients and bioactive substances. The bioactive feed additives, in particular algae, which support normal intestinal microflora and stimulate the body's defenses are considered as one of the most promising in the prevention and treatment of infections and as an alternative to feed antibiotics.

REFERENCES

1. Burtin P. Nutritional value of seaweeds. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, 2003, 2(4): 498-503.
2. Godfray H.C., Beddington J.R., Crute I.R., Haddad L., Lawrence D., Muir J.F., Pretty J., Robinson S., Thomas S.M., Toulmin C. Food security: the challenge of feeding 9 billion people. *Science*, 2010, 327(5967): 812-818 (doi: 10.1126/science.1185383).
3. Tilman D., Balzer C., Hill J., Befort B.L. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences of the United States of America*, 2011, 108(50): 20260-20264 (doi: 10.1073/pnas.1116437108).
4. Makkar H.P.S., Tran G., Heuze V., Guger-Reverdin S., Lessire M., Lebas F., Ankers P. Seaweeds

for livestock diets: a review. *Animal Feed Science and Technology*, 2016, 212: 1-17 (doi: 10.1016/j.anifeedsci.2015.09.018).
5. Sleptsov V.V. *Epokha nauki*, 2017, 9: 96-101 (in Russ.).
6. O'Sullivan L., Murphy B., McLoughlin P., Duggan P., Lawlor P.G., Hughes H., Gardiner G.E. Prebiotics from marine macroalgae for human and animal health applications. *Marine Drugs*, 2010, 8(7): 2038-2064 (doi: 10.3390/md8072038).
7. Kolomiets S.N., Egorova M.A., Farzutdinov R.Kh. *Zootekhniya*, 2020, 5: 14-17 (in Russ.).
8. Egorov I.A., Egorova T.A., Lenkova T.N., Vertiprakhov V.G., Manukyan V.A., Nikonov I.N., Grozina A.A., Filippova V.A., Yildirim E.A., Ilyina L.A., Dubrovin A.V., Laptev G.Yu. Poultry diets without antibiotics. ii. intestinal microbiota and performance of broiler (*Gallus gallus* L.) breeders fed diets with a phytobiotic. *Sel'skokhozyaistvennaya biologiya* [*Agricultural Biology*], 2019, 54(4): 798-809 (doi: 10.15389/agrobiology.2019.4.798eng).
9. Kim S.-K. *Handbook of marine microalgae: biotechnology advances*. K.A.S. Gomez, P. Gonzalez (eds.). Academic Press, UK, 2015.
10. van Krimpen M.M., Bikker P., van der Meer I.M., van der Peet-Schwering C.M.C., Vereijken J.M. Cultivation, processing and nutritional aspects for pigs and poultry of European protein sources as alternatives for imported soybean products. In: *Wageningen UR Livestock Research. No. 662*. Wageningen UR Livestock Research, Netherlands, 2013.
11. Kochish I.I., Myasnikova O.V., Martynov V.V. *Materialy Mezhdunarodnoy nauchno-prakticheskoy konferentsii «Molekulyarno-geneticheskie tekhnologii dlya analiza ekspressii genov produktivnosti i ustoychivosti k zabolevaniyam zhivotnykh»* [Proc. Int. Conf. «Molecular genetic technologies for analyzing the expression of genes for productivity and resistance to animal diseases», iss. 1]. Moscow, 2019, vyp. 1: 93-97 (in Russ.).
12. Buyarov V.S. Chervonova I.V., Yarovan N.I., Uchasov D.S., Sein O.B. *Probiotiki i prebiotiki v promyshlennom svinovodstve i ptitsevodstve: monografiya* [Probiotics and prebiotics in industrial pig and poultry farming: monograph]. Orel, 2014 (in Russ.).
13. Dubrovin A.V. Laptev G.Yu., Il'ina A.A., Filippova V.A., Yyldyrym E.A., Kochish I.I., Novikova O.B. *Veterinariya*, 2018, 12: 12-16 (in Russ.).
14. Kotarev V.I. Lyadova L.V., Morgunova V.I., Denisenko L.I. *Veterinarnyy farmakologicheskiy vestnik*, 2019, 3(8): 85-94 (doi: 10.17238/issn2541-8203.2019.3.85) (in Russ.).
15. Torshkov A.A., Fomichev Yu.P. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta*, 2010, 25(1): 172-175 (in Russ.).
16. Świątkiewicz S., Arczewska-Włosek A., Józefiak D. Application of microalgae biomass in poultry nutrition. *World's Poultry Science Journal*, 2016, 71(4): 663-672 (doi: 10.1017/S0043933915002457).
17. Windisch W.M., Rohrer E., Schedle K. Phytogenic feed additives to young piglets and poultry: mechanisms and application. In: *Phytogenics in animal nutrition: natural concepts to optimize gut health and performance*. T. Steiner (ed.). Nottingham, 2009: 19-38.
18. Garcia-Vaquero M., Rajauria G., O'Doherty J.V., Sweeney T. Polysaccharides from macroalgae: recent advances, innovative technologies and challenges in extraction and purification. *Food Research International,* 2017, 99(3): 1011-1020 (doi: 10.1016/j.foodres.2016.11.016).
19. Renuka N., Prasanna R., Sood A., Ahluwalia A.S., Bansal R., Babu S., Singh R., Shivay Y.S., Nain L. Exploring the efficacy of wastewater-grown microalgal biomass as a biofertilizer for wheat. *Environmental Science and Pollution research International,* 2015, 23(7): 6608-6620 (doi: 10.1007/s11356-015-5884-6).
20. Saha D., Bhattacharya S. Hydrocolloids as thickening and gelling agents in food: a critical review. *Journal of Food Science and Technology*, 2010, 47(6): 587-597 (doi: 10.1007/s13197-010-0162-6).
21. Schneider T., Ehrig K., Liewert I., Alban S. Interference with the CXCL12/CXCR4 axis as potential antitumor strategy: superiority of a sulfated galactofucan from the brown alga *Saccharina latissima* and fucoidan over heparins. *Glycobiology*, 2015, 25(8): 812-24 (doi: 10.1093/glycob/cwv022).
22. Audibert L., Fauchon M., Blanc N., Hauchard D., Gall E.A. Phenolic compounds in the brown seaweed *Ascophyllum nodosum*: distribution and radical-scavenging activities. *Phytochemical Analysis*, 2010, 21(5): 399-405 (doi: 10.1002/pca.1210).
23. Bittkau K.S., Neupane S., Alban S. Initial evaluation of six different brown algae species as source for crude bioactive fucoidans. *Algal Research*, 2020, 45: 101759 (doi: 10.1016/j.algal.2019.101759).
24. Devaney L., Henchion M., Regan Á. Good governance in the bioeconomy. *EuroChoices*, 2017, 16(2): 41-46 (doi: 10.1111/1746-692x.12141).
25. Atashrazm F., Lowenthal R.M., Woods G.M., Holloway A.F., Dickinson J.L. Fucoidan and cancer: a multifunctional molecule with anti-tumor potential. *Marine Drugs*, 2015, 13(4): 2327-46 (doi: 10.3390/md13042327).
26. Jr. Goh L.P., Loh S.P., Fatimah M.Y., Perumal K. Bioaccessibility of carotenoids and tocopherols in marine microalgae, *Nannochloropsis* sp. and *Chaetoceros* sp. *Malaysian Journal of Nutrition*, 2009, 15(1): 77-86.
27. Heffernan N., Brunton N.P., FitzGerald R.J., Smyth T.J. Profiling of the molecular weight and structural isomer abundance of macroalgae-derived phlorotannins. *Marine Drugs*, 2015, 13(1): 509-528 (doi: 10.3390/md13010509).
28. Heffernan N., Smyth T.J., Soler-Villa A., Fitzgerald R.J., Brunton N.P. Phenolic content and

antioxidant activity of fractions obtained from selected Irish macroalgae species (*Laminaria digitata*, *Fucus serratus*, *Gracilaria gracilis and Codium fragile)*. *Journal of Applied Phycology*, 2015, 27(1): 519-530 (doi: 10.1007/s10811-014-0291-9).
29. Kılınç B., Cirik S., Turan G., Tekogul H., Koru E. Seaweeds for food and industrial applications. In: *Food industry*. I. Muzzalupo (eds.). InTech, 2012 (doi: 10.5772/53172).
30. Liu H., Gu L. Phlorotannins from brown algae (*Fucus vesiculosus*) inhibited the formation of advanced glycation end products by scavenging reactive carbonyls. *Journal of Agricultural and Food Chemistry*, 2012, 60(5): 1326-34 (doi: 10.1021/jf204112f).
31. Nakamura T., Nagayama K., Uchida K., Tanaka R. Antioxidant activity of phlorotannins isolated from brown alga *Eisenia bicyclis. Fisheries Science*, 1996, 62(6): 923-926 (doi: 10.2331/fishsci.62.923).
32. Pozharitskaya O.N., Obluchinskaya E.D., Shikov A.N. Mechanisms of bioactivities of *Fucoidan* from the brown seaweed *Fucus vesiculosus* L. of the Barents Sea. *Marine Drugs*, 2020, 18(5): 275(doi: 10.3390/md18050275).
33. Ragan M.A., Jensen A. Quantitative studies on brown algal phenols. II. Seasonal variation in polyphenol content of *Ascophyllum nodosum* (L.) Le Jol. and *Fucus vesiculosus* (L.). *Journal of Experimental Marine Biology and Ecology*, 1987, 34(3): 245-258 (doi: 10.1016/S0022-0981(78)80006-9).
34. Puspita M., Deniel M., Widowati I., Radjasa O.K., Douzenel P., Marty C., Vandanjon L., Bedoux G., Bourgougnon N. Total phenolic content and biological activities of enzymatic extracts from *Sargassum muticum* (Yendo) Fensholt. *Journal of Applied Phycology*, 2017, 29(5): 2521-2537 (doi: 10.1007/s10811-017-1086-6).
35. El Gamal A.A. Biological importance of marine algae. *Saudi Pharmaceutical Jorunal*, 2010, 18(1): 1-25 (doi: 10.1016/j.jsps.2009.12.001).
36. Hayes M. Food proteins and bioactive peptides: new and novel sources, characterisation strategies and applications. *Foods*, 2018, 7(3): 38 (doi: 10.3390/foods7030038).
37. Yip Z.T., Quek R.Z.B., Huang D. Historical biogeography of the widespread macroalga *Sargassum* (*Fucales*, *Phaeophyceae*). *J. Phycol.*, 2020, 56(2): 300-309 (doi: 10.1111/jpy.12945).
38. Murty U.S., Banerjee A.K. Seaweed: the wealth of oceans. In: *Handbook of marine macroalgae: biotechnology and applied phycology*. S.-K. Kim (ed.). Cambridge, 2012: 36-43 (doi: 10.1002/9781119977087.ch2).
39. Edwards M., Hanniffy D., Heesch S., Hernández-Kantún J., Moniz M., Queguineur B., Ratcliff J., Soler-Vila A., Wan A. *Macroalgae fact-sheets*. A. Soler-Vila, M. Moniz (eds.). Irish Seaweed Research Group, Ryan Institute, NUI Galway, 2012.
40. Misurcova L. Chemical composition of seaweeds. In: *Handbook of marine macroalgae: biotechnology and applied phycology*. S.-K. Kim (ed.). John Wiley & Sons, Ltd., 2012 (doi: 10.1002/9781119977087.ch7).
41. Corino C., Modina S.C., Giancamillo A.D., Chiapparini S., Rossi R. Seaweeds in pig nutrition. *Animals*, 2019, 9(12): 1126 (doi: 10.3390/ani9121126).
42. Azenha I. *Cultivo e Avaliação Nutricional de Ulva sp. Comparação com Exemplares Recolhidos em Ambiente Natural. Bachelor's Thesis Escola Superior Agrária de Coimbra*. Coimbra, Portugal, 2019.
43. Evans F.D., Critchley A.T. Seaweeds for animal production use. *Journal of Applied Phycology,* 2013, 26(2): 891-899 (doi: 10.1007/s10811-013-0162-9).
44. Spruijt J., van der Weide R., van Krimpen M. Opportunities for microalgae as ingredient in animal diets. In: *Application Centre for Renewable Resource*. R. van der Weide (ed.). Wageningen UR, Netherlands, 2016.
45. Abudabos A.M. Okab A., Aljumaah R.S., Samara E.M., Abdoun K.A., Al-Haidar A.A. Nutritional value of greenseaweed (*Ulva lactuca)* for broiler chickens. *Italian Journal of Animal Science*, 2012, 12(2): 177-181 (doi: 10.4081/ijas.2013.e28).
46. Wang S.B., Shi X.P., Zhou C.F., Lin Y.T. *Enteromorpha prolifera*: effects on performance, carcass quality and small intestinal digestive enzyme activities of broilers. *Chinese Journal of Animal Nutrition*, 2013, 25(6): 1332-1337.
47. Wang S.B., Jia Y.H., Wang F.H., Lin Y.T. *Enteromorpha prolifera* supplemental level: effects on laying performance, egg quality, immune function and microflora in feces of laying hens. *Chinese Journal of Animal Nutrition*, 2013, 25(6): 1346-1352.
48. Bradbury E.J. Wilkinson S.J., Cronin G.M., Walk C., Cowieson A. The effect of marine calcium source on broiler leg integrity. In: *Australian poultry science symposium*. E.J. Bradbury (ed.). Poultry Research Foundation, Australia, 2012, 23: 85-88.
49. Al-Harthi M.A. Sexual maturity and performance of pullets fed different preparations and concentrations of brown marine algae (*Sargassum dentifebium*) in pre-laying and early laying periods. *Italian Journal of Animal Science*, 2014, 13(1): 3102 (doi: 10.4081/ijas.2014.3102).
50. Al-Harthi M.A., El-Deek A.A. The effects of preparing methods and enzyme supplementation on the utilization of brown marine algae (*Sargassum dentifebium*) meal in the diet of laying hens. *Italian Journal of Animal Science,* 2011, 10(48): 195-203 (doi: 10.4081/ijas.2011.e48).
51. Al-Harthi M.A., El-Deek A.A. Effect of different dietary concentrations of brown marine algae (*Sargassum dentifebium*) prepared by different methods on plasma and yolk lipid profiles, yolk total carotene and lutein plus zeaxanthin of laying hens. *Italian Journal of Animal Science*, 2012, 11(4): 347-353 (doi: 10.4081/ijas.2012.e64).

52. El-Deek A.A., Al-Harthi M.A., Abdalla A.A., Elbanoby M.M. The use of brown algae meal in finisher broiler diets. *Egypt Poultry Science Journal*, 2011, 31(IV): 767-781.
53. Kulshreshtha G., Rathgeber B., Stratton G., Thomas N., Evans F., Critchley A., Hafting J., Prithiviraj B. Feed supplementation with red seaweeds, *Chondus crispus* and *Sarcodiotheca gaudichaudii*, affects performance, egg quality, and gut microbiota of layer hens. *Poultry Science*, 2014, 93(12): 2991-3001 (doi: 10.3382/ps.2014-04200).
54. Kulshreshtha G., Rathgeber B., MacIsaac J., Boulianne M., Brigitte L., Stratton G., Thomas N.A., Critchley A.T., Hafting J., Prithiviraj B. Feed supplementation with red seaweeds, *Chondrus crispus* and *Sarcodiotheca gaudichaudii*, reduce *Salmonella enteritidis* in laying hens. *Frontiers in Microbiology*, 2017, 8: 567 (doi: 10.3389/fmicb.2017.00567).
55. Ngo D.-H., Kim S.-K. Sulfated polysaccharides as bioactive agents from marine algae. *International Journal of Biological Macromolecules*, 2013, 62: 70-75 (doi: 10.1016/j.ijbiomac.2013.08.036).
56. Mariey Y.A., Samak H., Ibrahem M. Effect of using *Spirulina platensis* algae as feed additive for poultry diets. *Egyptian Poultry Science Journal*, 2012, 32(1): 201-215.
57. Kulshreshtha G., Borza T., Rathgeber B., Stratton G.S., Thomas N.A., Crithley A., Hafting J., Prithiviraj B. Red seaweeds *Sarcodiotheca gaudichaudii* and *Chondrus crispus* down regulate virulence factors of *Salmonella enteritidis* and induce immune responses in *Caenorhabditis elegans*. *Frontiers in Microbiology*, 2016, 7: 1-12 (doi: 10.3389/fmicb.2016.00421).
58. Manor M.L., Derksen T.J., Magnuson A.D., Raza F., Lei X.G. Inclusion of dietary defatted microalgae dose-dependently enriches ω-3 fatty acids in egg yolk and tissues of laying hens. *The Journal of Nutrition*, 2019, 149(6): 942-950 (doi: 10.1093/jn/nxz032).
59. Sweeney T., Meredith H., Vigors S., McDonnell M.J., Ryan M., Thornton K., O'Doherty J.V. Extract of laminarin and laminarin/fucoidan from the marine macroalgal species *Laminaria digitata* improved growth rate and intestinal structure in young chicks, but does not influence *Campylobacter jejuni* collonisation. *Animal Feed Science and Technology*, 2017, 232(4): 71-79 (doi: 10.1016/j.anifeedsci.2017.08.001).
60. Erickson P.S., Marston S.P., Gemmel M., Deming J., Cabral R.G., Murphy M.R., Marden J.I. Short communication: kelp taste preferences by dairy calves. *Journal of Dairy Science*, 2012, 95(2): 856-858 (doi: 10.3168/jds.2011-4826).
61. Bach S.J., Wang Y., Mcallister T.A. Effect of feeding sun-dried seaweed (*Ascophyllum nodosum*) on fecal shedding of *Escherichia coli* O157:H7 by feedlot cattle and on growth performance of lambs. *Animal Feed Science and Technology*, 2008, 142(1-2): 17-32 (doi: 10.1016/j.anifeedsci.2007.05.033).
62. Lopez C.C., Serio A., Rossi C., Mazzarrino G., Marchetti S., Castellani F., Grotta L., Fiorentino F.P., Paparella A., Martino G. Effect of diet supplementation with *Ascophyllum nodosum* on cow milk composition and microbiota. *Journal of Dairy Science*, 2016, 99(8): 6285-6297 (doi: 10.3168/jds.2015-10837).
63. Konovalov A.V., Flerova E.A., Zarubin A.V., Bogdanova A.A. *Vestnik APK Verkhnevolzh'ya*, 2012, 1(17): 46-49 (in Russ.).
64. Garcés C.N., Vela D., Mullo A., Cabezas V., Alvear A., Ponce C. Spirulina supplementation during the transition period by grazing dairy cattle at tropical highland conditions. *Tropical Animal Health and Production*, 2019, 51(2): 477-480 (doi: 10.1007/s11250-018-1691-7).
65. Petryakov V.V. *Nauchnyy al'manakh*, 2016, 6-2(19): 442-445 (in Russ.).
66. Mekhanikova M.V., Tret'yakov E.A., Kulakova T.S. *Molochnokhozyaystvennyy vestnik*, 2016, 1(21): 35-42 (in Russ.).
67. Roque B.M., Brooke C.G., Ladau J., Polley T., Marsh L.J., Najafi N., Pandey P., Singh L., Kinley R., Salwen J.R., Eloe-Fadrosh E., Kebreab E., Hess M. Effect of the macroalgae *Asparagopsis taxiformis* on methane production and rumen microbiome assemblage. *Animal Microbiome*, 2019, 1: 3 (doi: 10.1186/s42523-019-0004-4).
68. Maghin F., Ratti S., Corino C. Biological functions and health promoting effects of brown seaweeds in swine nutrition. *Journal of Dairy, Veterinary & Animal Research*, 2014, 1(1): 14-16 (doi: 10.15406/jdvar.2014.01.00005).
69. Wan J., Jiang F., Xu Q., Chen D., He J. Alginic acid oligosaccharide accelerates weaned pig growth through regulating antioxidant capacity, immunity and intestinal development. *RSC Advances*, 2016, 90: 87026-87035 (doi: 10.1039/c6ra18135j).
70. Choi Y., Hosseindoust A., Goel A., Lee S., Jha P.K., Kwon I.K., Chae B.-J. Effects of *Ecklonia cava* as fucoidan-rich algae on growth performance, nutrient digestibility, intestinal morphology and caecal microflora in weanling pigs. *Asian-Australasian Journal of Animal Sciences*, 2017, 30(1): 64-70 (doi: 10.5713/ajas.16.0102).
71. Dell'Anno M., Sotira S., Rebucci R., Reggi S., Castinglioni B., Rossi L. In vitro evaluation of antimicrobial and antioxidant activities of algal extracts. *Italian Journal of Animal Science*, 2020, 19(1): 103-113 (doi: 10.1080/1828051X.2019.1703563).
72. Azizi A.F.N., Miyazaki R., Yumito T., Ohashi Y., Uno S., Miyajima U., Kumamoto M., Uchiyama S., Yasuda M. Effect of maternal supplementation with seaweed powder on immune status of liver and lymphoid organs of piglets. *The Journal of Veterinary Medical Science*, 2018, 80(1): 8-12 (doi: 10.1292/jvms.17-0537).
73. Nedeva R., Jordanova G., Kistanova E., Shumkov K., Georgiev B., Abadgieva D., Kacheva D., Shimkus A., Shimkine A. Effect of the addition of *Spirulina platensis* on the productivity and

some blood parameters on growing pigs. *Bulgarian Journal of Agricultural Science*, 2014, 20(3): 680-684.

74. McDonnell P., Figat S., O'Doherty J.V. The effect of dietary laminarin and fucoidan in the diet of the weanling piglet on performance, selected faecal microbial populations and volatile fatty acid concentrations. *Animal*, 2010, 4(4): 579-585 (doi: 10.1017/S1751731109991376).
75. Derek N., Ovyn A., De Smet S. In vitro assessment of the effect of intact marine brown macro-algae *Ascophyllum nodosum* on the gut flora of piglets. *Livestock Science*, 2010, 133(1-3): 154-156 (doi: 10.1016/j.livsci.2010.06.051).
76. Katayama M., Fukuda T., Okamura T., Suzuki E., Tamura K., Shimizu Y., Suda Y., Suzuki K. Effect of dietary addition of seaweed and licorice on the immune performance of pigs. *Animal Science Journal*, 2011, 82(2): 274-281 (doi: 10.1111/j.1740-0929.2010.00826.x).
77. Panin A.N., Komarov A.A., Kulikovskiy A.V., Makarov D.A. *Veterinariya i zootekhniya*, 2017, 5: 18-24 (in Russ.).
78. Vsemirnaya organizatsiya zdorov'ya zhivotnykh. *Kodeks zdorov'ya nazemnykh zhivotnykh, 28 izdanie*. Rue de Prony, Paris, 2019 (in Russ.).
79. Centers for Disease Control and Prevention (U.S.). *Antibiotic resistance threats in the United States, 2013 (2013)*. Available: https://stacks.cdc.gov/view/cdc/20705. No date.
80. Korotkevich Yu.V., Efimochkina N.R., Sheveleva S.A. *Materialy 2-y Mezhdunarodnoy nauchno-prakticheskoy konferentsii «Sovremennye tekhnologii produktov pitaniya»* [Proc. 2 Int. Conf. «Modern food technologies»]. Kursk, 2015, 78-81 (in Russ.).
81. European Food Safety Authority (EFSA). The European Union summary report on trends and sources of zoonoses, zoonotic agents and foodborne outbreaks in 2013. *European Food Safety Authority Journal*, 2015, 13(1): 3991 (doi: 10.2903/j.efsa.2015.3991).
82. Meunier M., Guyard-Nicodeme M., Dory D., Chemaly M. Control strategies against *Campylobacter* at the poultry production level: biosecurity measures, feed additives and vaccination. *Journal of Applied Microbiology*, 2016, 120(5): 1139-1173 (doi: 10.1111/jam.12986).
83. Efimochkina N.R., Korotkevich Yu.V., Stetsenko V.V., Pichugina T.V., Bykova I.V., Markova Yu.M., Minaeva L.P., Sheveleva S.A. *Voprosy pitaniya*, 2017, 86(1): 17-27 (doi: 10.24411/0042-8833-2017-00016) (in Russ.).
84. Sukhinin A.A., Rozhdestvenskaya T.N., Pankratov S.V., Smirnova L.I., Makavchik S.A. *Veterinariya i kormlenie*, 2021, 3: 52-54 (in Russ.).
85. Cumashi A., Ushakova N.A., Preobrazhenskaya M.E., D'Incecco A., Piccoli A., Totani L., Tinari N., Morozevich G.E., Berman A.E., Bilan M.I., Usov A.I., Ustyuzhanina N.E., Grachev A.A., Sanderson C.J., Kelly M., Rabinovich G.A., Lacobelli S. A comparative study of the anti-inflammatory, anticoagulant, antiangiogenic and antiadhesive activities of nine different fucoidans from brown seaweeds. *Glycobiology*, 2007, 17(5): 541-552 (doi: 10.1093/glycob/cwm014).
86. Morua V.K., Kim J., Kim E.-K. Algal fucoidan: structural and size-dependent bioactivities and their perspectives. *Applied Microbiology and Biotechnology*, 2012, 93(1): 71-82 (doi: 10.1007/s00253-011-3666-8).
87. Zinov'ev E.V., Luk'yanov S.A., Tsygan V.N., Kul'minskaya A.A., Lapina I.M., Zhurishkina E.V., Lopatin I.M., Asadulaev M.S., Artsimovich I.V., Kostyakov D.V., Paneyakh M.B., Shabunin A.S., Zubov V.V., Zhilin A.A., Davletova L.A., Stekol'shchikova E.A. *Vestnik Rossiyskoy voenno-meditsinskoy akademii*, 2019, 1(65): 148-152 (in Russ.).
88. Potoroko I.Yu., Uskova D.G., Paymulina A.V., Bagale U. *Vestnik Yuzhno-Ural'skogo gosudarstvennogo universiteta. Seriya: Pishchevye i Biotekhnologii*, 2019, 7(1): 58-70 (doi: 10.14529/food190107) (in Russ.).
89. Bogolitsyn K.G., Kaplitsin P.A., Pochtovalova A.S. Amino-acid composition of arctic brown algae. *Chemistry of Natural Compounds*, 2014, 49(6): 1110-1113 (doi: 10.1007/s10600-014-0831-1).
90. Shibata T., Ishimaru K., Kawaguchi S., Yoshikawa H., Hama Y. Antioxidant activities of phlorotannins isolated from Japanese *Laminariaceae*. *Journal of Applied Phycology*, 2007, 20(5): 705-711 (doi: 10.1007/s10811-007-9254-8).
91. Ryu Y.B., Jeong H.J., Yoon S.Y., Park J.Y., Kim Y.M., Park S.J., Rho M.C., Kim S.J., Lee W.S. Influenza virus neuraminidase inhibitory activity of phlorotannins from the edible brown alga *Ecklonia cava*. *Journal of Agricultural and Food Chemistry*, 2011, 59(12): 6467-6473 (doi: 10.1021/jf2007248).
92. Lezcano V., Fernández C., Parodi E.R., Morelli S. Antitumor and antioxidant activity of the freshwater macroalga *Cladophora surera*. *Journal of Applied Phycology*, 2018, 30(5): 2913-2921 (doi: 10.1007/s10811-018-1422-5).
93. Kojima-Yuasa A. Biological and pharmacological effects of polyphenolic compounds from *Ecklonia cava*. In: *Polyphenols: mechanisms of action in human health and disease*. R.R. Watson, V.R. Preedy, S. Zibadi (eds.). Academic Press, London, 2018: 41-52 (doi: 10.1016/B978-0-12-813006-3.00005-2).
94. Lee M.H., Lee K.B., Oh S.M., Lee B.H., Chee H.Y. Antifungal activities of dieckol isolated from the marine brown alga *Ecklonia cava* against *Trichophyton rubrum*. *Journal of the Korean Society for Applied Biological Chemistry*, 2010, 53(4): 504-507 (doi: 10.3839/jksabc.2010.076).
95. Kim H.-J., Dasagrandhi C., Kim S.-H., Kim B.-G, Eom S.-H., Kim Y.-M. In vitro antibacterial activity of phlorotannins from edible brown algae, *Eisenia bicyclis* against streptomycin-resistant

Listeria monocytogenes. *Indian Journal of Microbiology*, 2018, 58(1): 105-108 (doi: 10.1007/s12088-017-0693-x).

96. Barbosa M., Lopes G., Valentro P., Ferreres F., Gil-Izquierdo Á., Pereira D.M., Andrade P.B. Edible seaweeds' phlorotannins in allergy: a natural multi-target approach. *Food Chemistry*, 2018, 265:233-241 (doi: 10.1016/j.foodchem.2018.05.074).