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EUROPEAN EXPERIENCE IN SPIRULINA CULTIVATION AS AN INNOVATIVE DIRECTION IN AQUACULTURE

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This scientific article presents material highlighting the algorithm of complex biological and technological aspects in aquaculture with the aim of obtaining products as close as possible to ecologically safe, taking into account the course of European integration of Ukrainian aquaculture. The main part of the study is based on a review of the literature, research and personal practical experience of the author of the article, obtained during a professional internship at the farm «Spiruline des Landes» (France).

The presented results of research and analysis of the technological features of spirulina (Spirulina platensis) cultivation with the integration of European methods demonstrate the specificity of the ecological and biological nature of cyanobacteria, ensuring optimal reproduction and growth in salt and fresh water.

The comprehensively analyzed information and research material confirms that the cultivation of spirulina is today considered an innovative direction in many areas. Laboratory studies have shown that spirulina (Spirulina platensis) is the most valuable component for aquaculture due to its unique composition, rich in proteins, vitamins, minerals and antioxidants. Ready-made products with spirulina are used in the food industry to create functional products that promote health and prevent various diseases.

The practical value of using spirulina in feeding hydrobionts is noted in the article. Its natural composition is substantiated as a valuable vegetable feed for fish due to the presence in the chemical composition of protein in high concentrations (>20-40%), carotenoids and vitamins, which improves digestion, immunity and brightness of color. The article substantiates that spirulina has a complex positive effect for most aquaculture facilities due to its absorption by the body.

Key words: *aquaculture, cyanobacteria, natural food for fish, stocking of reservoirs, technologies, RAS (recirculating aquaculture systems), natural reservoirs.*

Головко А.А. Європейський досвід вирощування спіруліни як інноваційний напрямок в аквакультурі

У цій науковій статті представлено матеріал, що висвітлює алгоритм складних біолого-технологічних аспектів в аквакультурі з метою отримання продукції максимально наближеної до екологічно безпечної з урахуванням курсу європейської інтеграції української аквакультури. Основна частина дослідження базується на огляді літератури, досліджень та особистого практичного досвіду автора статті, отриманого під час професійного стажування на фермі «Spiruline des Landes» (Франція).

Представлені результати досліджень та аналізу технологічних особливостей культивування спіруліни (Spirulina platensis) з інтеграцією європейських методик демонструють специфічність еколого-біологічного характеру ціанобактерій, з забезпеченням оптимального розмноження та росту у солоній та прісній воді.

Комплексно проаналізований інформаційний, науково-дослідний матеріал підтверджує, що вирощування спіруліни сьогодні вважається інноваційним напрямком у багатьох сферах. Встановлено лабораторними дослідженнями, що спіруліна (Spirulina platensis) є найціннішим компонентом для аквакультури завдяки своєму унікальному складу, багатому на білки, вітаміни, мінерали та антиоксиданти. Готові продукти зі спіруліною *використовуються в харчовій промисловості для створення функціональних продуктів, що сприяють здоров'ю та запобігають різним захворюванням.*

Відмічена в статті практична цінність використання спіруліни при підгодівлі гідробіонтів. Обґрунтовано її природний склад як цінний рослинний корм для риб через наявність у хімічному складі білку у високих концентраціях (>20-40%), каротиноїдів та вітамінів, що покращує травлення, імунітет та яскравість забарвлення. В статті обґрунтовано, що спіруліна має комплексну позитивну дію для більшості об'єктів аквакультури через її засвоєння організмом.

Ключові слова: *аквакультура, ціанобактерії, природний корм для риб, зариблення водойм, технології, РАС (рециркуляційні аквакультурні системи), природні водойми.*

Problem statement. Ukraine has the potential of pre-war times, in particular, the South, where the water fund and resources were distinguished by high productivity and efficiency of the fishing industry. However, climate change and prolonged hostilities inevitably exert negative destructive pressure on ecosystems. Rationality and recovery are among the vectors of the post-war recovery of the aquaculture industry. A comprehensive approach will ensure the effectiveness of using elements of European experience, including when cultivating spirulina.

The problem is to provide fish with complete protein, where spirulina is a natural source of a set of amino acids and biologically active substances. In addition, its use as a source of alternative forms of energy also contributes to the development of the EU. Ukrainian producers aim to restore the production potential of aqua farms and enterprises and stabilize the production of aquaculture products with organic characteristics as close as possible.

Relevance of the research topic and scientific novelty. The scientific novelty and relevance of the research of the work consists in the cultivation of spirulina in pools using the Zarrouk nutrient medium, which is considered economically feasible in general, and especially appropriate in post-war reconstruction. Experience in growing spirulina was obtained on the basis of a French farm, and it can be borrowed by Ukrainians.

Analysis of remaining research and publications. Spirulina is known for its high protein content, which makes it an important food source for humans and animals. The protein composition of spirulina is not only high in quantity, but also rich in all the necessary amino acids, which makes it a complete source of proteins.

Spirulina contains 55% to 70% protein by dry weight, which is one of the the highest indicators among known food products. Protein content can vary depending on cultivation conditions, harvest time and light intensity during growth [1].

Spirulina protein is easily absorbed by the body due to the absence of fibers in its cell walls. This means that the amino acids of spirulina quickly and efficiently absorbed, providing the body with everything necessary nutrients. Spirulina has a coefficient digestibility of protein at the level of 85-95%, which is a higher indicator compared to other sources of protein, such as meat [2].

In aquaculture, many factors are of great importance when it comes to high-quality cultivation of aquatic organisms. First of all, the hydrochemical factor of water bodies and the feed factor occupy the first place.

As the authors' research shows, not only the hydrochemical regime of water bodies, but also the food factor contributes to the formation of morphometric indicators of aquatic organisms. In aquaculture, there are many experimental works on the analysis and study of the influence of biologically active additives of various nature, natural feeds, phytoplankton when feeding fish, on their organism, development rate, meristic and plastic parameters, etc. [3, 6]. Attention should be paid to the promising feed and food additive phytoplankton – spirulina. It is known that spirulina (*Spirulina Platensis*) is a promising feed and food raw material, which is rich in protein, has a balanced amino acid composition, contains vitamins and minerals [4, 9]. The literature contains results of using various methods of processing spirulina to achieve maximum effect when using it as a nutritional supplement [6, 7].

Spirulina platensis is an old prokaryotic cyanobacteria that was rediscovered in the last few decades [7], and Spirulina is a unicellular organism that has the ability to grow under different environmental conditions [7]. Spirulina was first isolated in the 16th century from Lake Texcoco in Mexico [6, 7]. National Aeronautics and Space Administration (NASA) studied the cultivation of *Spirulina platensis* as a food source [7,9], and the World Health Organization (WHO) reported that *Spirulina platensis* has no risk and is a good food supplement for health [8]. Spirulina platensis has a protein content range of 50% – 70% with 5% – 10% lipids and 10% – 20% carbohydrates, and all essential amino acids in complete balance; it also has 10 vitamins, especially vitamin B12, pro-vitamin A (β-carotene), and minerals such as iron [10, 11, 12]. Table 1 shows the percentage content of the main amino acids in the composition of spirulina: Essential amino acids are marked separately with (*).

Table 1

Percentage content of basic amino acids in spirulina

Amino acid	**Percentage of the total amino acids (%)**
Alanine	7.9
Arginine	7.3
Aspartic acid	10.1
Cysteine	1.2
Glutamic acid	14.7
Glycine	5.4
Histidine*	1.9
Isoleucine*	5.6
Leucine*	8.7
Lysine*	5.3
Methionine*	2.0
Phenylalanine*	4.9
Proline	4.2
Serin	5.2
Threonine*	3.4
Tryptophan*	1.6
Tyrosine	4.5
Valine*	6.1

Spirulina proteins have a high biological value due to the balanced composition of amino acids. The high concentration of amino acids such as leucine, isoleucine and valine makes spirulina a valuable product for athletes and people with an active lifestyle [13]. And also for fish as an additive to food or as part of compound feed.

Materials and research methods. Experience in growing spirulina was gained at the “Spiruline des Landes” farm, at the address: Quartier, Rte de Lahitte, 40160 Parent-is-en-Born, France (Fig. 1) [14].

Fig. 1. Farm "Spiruline des Landes"

Spirulina platensis was cultured in pools – greenhouses using Zarrouk medium [15] containing (g.l-1) 2.5 NaNO3, 16.8 NaHCO3, 0.5 K2HPO4, 1.0 K2SO4, 1.0 NaCl, 0.04 CaCl2, 0.08 Na2EDTA, 0.2MgSO4·7H2O, 0.01FeSO4·7H2O and 1.0 ml of A5 micronutrient solution. at a temperature of 32˚C, pH 10.5, sunlight (shade) of ~25 K-lux, and aeration using an aquarium air pump. Laboratory equipment was used to analyze the development of microalgae: an electron microscope, a glass slide, laboratory test tubes, and a pH meter for rapid analysis.

Results. Comprehensive research results during the internship of the author of the scientific article demonstrated, using the example of the analysis of the company "La Spirulina des Landes" (France), that the average area of the spirulina cultivation and processing sector is 600 m^2. A comparison of technological aspects in the cultivation of spirulina demonstrated that European models have differences in the relative compactness of production. For example, the described enterprise has a section (sectors) consisting of three production greenhouses, a collection and packaging laboratory. Production works on a 100% recirculating aquaculture system (RAS).

Spiruline des Landes is grown in greenhouses with full respect for the environment. It is still not widely known in the cultivation of microalgae, which is very rich in protein (60-70%), iron, vitamins and mainly trace elements. It brings many benefits to the body. It is also very popular in aquaculture [16].

The results of the analysis of technological aspects of spirulina cultivation according to European standards demonstrated a logical sequence and the presence of the following components in the technological map:

1. water tank;
2. nutrient environment;
3 harvesting tools;
4 mother culture of spirulina for cultivation;
5. place for drying and processing.

When using a working nutrient medium for spirulina, the following components are used:

– sodium bicarbonate;
– ammonium phosphate;

– sea salt;
– potassium nitrate
– iron.

For the mother water medium, the water should be non-chlorinated, and the nutrients should be diluted in the proportion of 16 g/l.

When organizing the initial stages of production, the specialist checks the quality of the raw materials, in particular the water and nutrients used to grow spirulina. The water must be clean, without heavy metals and other harmful impurities. The use of clean and safe nutrients provides optimal conditions for the growth of spirulina [17].

The analysis of hydrochemical parameters showed that during the cultivation of spirulina it is necessary to constantly control the main parameters such as temperature, pH, concentration of nutrients and light level. The use of automated control systems makes it possible to ensure stable growing conditions and avoid contamination by unwanted microorganisms [18].

Technological aspects of spirulina cultivation with emphasis on the composition of Zarrouk's nutrient medium involve nutrient modification to minimize production costs at the outdoor growing stage. Outdoor nutrition was employed using urea as a nitrogen source instead of sodium nitrate at a final concentration of 1.8 g.l-1 that represented two-fold of nitrogen content of sodium nitrate, aiming to increase the carbon feeding. In addition, corn steam liqueur was added at 0.7 g.l-1 to increase organic carbon content with low NaHCO3 use (El-Sayed et al., 2015). Phosphorus was supplemented from 0.2 ml.l-1 of commercial phosphoric acid (84% P2O5), while potassium was added as 1.0 g.l-1 of a commercial potassium sulfate (52% K2O). Sodium chloride at 1.0 g.l-1 was added. Sodium bicarbonate was minimized to be 5.0 g.l-1 from commercial grade with 0.025 g.l-1 ferrous sulfate. Re-cycling water after harvesting minimized some of the required nutrients mainly sodium chloride. Acid reaction was adjusted using commercial potassium hydroxide.

Analysis of the next stage of the technological map of spirulina cultivation showed that special pH strips are used to check the maturity of the algae. The algae is usually harvested in the morning because the concentration of phycocyanin, the phytonutrient that makes spirulina so beneficial, is highest then.

Algal culture collection methods vary considerably depending on the method of cultivation and the strain. Gravity extraction is universally performed in the presence of fluctuating agents such as aluminum sulfate, which alters the reaction of the medium, especially with spirulina cultures. Observation of this process showed that, in this case, the addition of ferrous sulfate led to an increase in the size of the colonies, which, in turn, increased the separation efficiency.

The results of the equipment and equipment involved in the process of spirulina cultivation demonstrated that one of the effective collection methods is the use of a continuous separation apparatus, namely a self-cleaning one. This study used continuous collection (Westevalia Separator 15,000 l/h centrifuge). The algal suspension was pumped into the reservoir tank through a 75 mm diameter plastic valve to ensure continuous operation. Drainage water was recirculated into a large pond with a volume of 45 m3.

The technological works included maintenance of the pools with growth volume analysis, daily cleaning, turbulence control and feeding. The growth volume was adjusted at the time of the first inoculation to be equivalent to the growth rate by dilution with tap water and appropriate nutrients. Filling the growth volume to the full capacity of the pools was carried out as mentioned earlier. A major consideration in pond maintenance was cleaning the pond edges, which was suggested because of the high growth rate to prevent larval growth that could destroy the culture.

Conclusion. According to the experience gained during an internship abroad and a thorough study of the technology of spirulina cultivation in farm conditions in France, we can come to the conclusion: that spirulina has a wide range of use for both humans and hydrobionts; has a valuable composition due to the presence of proteins and amino acids; is widely used in all countries of the world, but there is no popularity of spirulina cultivation specifically in Ukraine.

Because this natural feed can act as an alternative source of protein in aquaculture. During the post-war restoration of the water areas of the South of Ukraine, complex solutions using integral methods in the combination of natural water bodies and industrial aquaculture will ensure the sustainable development of the industry. In the context of reducing the load on the ecosystem due to the use of natural components (for example, spirulina), this direction acquires practical importance for the sustainable development of Ukrainian aquaculture.

Ukrainian aquaculture producers will have the opportunity to integrate into the technological map of spirulina cultivation the European approach, where all production is combined on one area. From cultivation to processing, processing and packaging of finished products. This approach will strengthen the commercial sector, openness to consumers and the possibility of maximum control of the production cycle.

The following studies are planned for experimental work on the use of natural components to optimize the growth of young fish for the purpose of stocking reservoirs in the Southern region of Ukraine.

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