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CONFERENCE BOOK

ICHEAS 7TH INTERNATIONAL CONFERENCE ON HEALTH, ENGINEERING AND APPLIED SCIENCES

JUNE 28 - 30, 2024- SARAJEVO

ISBN: 978-625-6283-35-0

ACADEMY GLOBAL PUBLISHING HOUSE

ICHEAS 7TH INTERNATIONAL CONFERENCE ON HEALTH, ENGINEERING AND APPLIED SCIENCES
JUNE 28 - 30, 2024 – SARAJEVO

Edited By
PROF. DR. NAILE BILGILI

USE OF *Arthrospira platensis* IN THE DEVELOPMENT OF FUNCTIONAL FOODS

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ABSTRACT

Because of its high protein content and rich nutritional profile, which includes essential amino acids and bioactive compounds like biliproteins and C-phycocyanin with antioxidant properties, *Arthrospira platensis*, also known as *spirulina*, is becoming more and more recognized as a potent food supplement. It also provides a major source of carotenoids, xanthophylls, phyto pigments, and vitamins A, E, B1, B7, and B8. It has a low fat content but is rich in linolenic and γ-linolenic acids, which are essential for human health. Rich in minerals such as iron, calcium and potassium, A. platensis can improve bone health and overall health. It ensures easy digestion thanks to its high carbohydrate content and lack of cellulose. *Arthrospira platensis* is known for its immunomodulatory, antioxidant, and hypocholesterolemic properties. It has potential uses in the development of functional foods and as a medicine to treat a range of non-communicable diseases. Its effectiveness in addressing protein and iron deficiency anemia through fortification of traditional foods has been demonstrated by recent research, highlighting its bioavailability and potential to improve public health. *Arthrospira platensis* is one of the microalgae increasingly used to improve the nutritional value and mouthfeel of food products. This is a sustainable way to address global health challenges and advance the field of producing functional foods.

Keywords: *Arthrospira platensis*, functional food, food industry, sustainable nutrition

1. INTRODUCTION

With increasing human populations, nutritional needs also increase. In the context of limited food resources and climate change, wetlands, which are vital to the food web, are also endangered (Zariç and Çelekli 2023). The exacerbation of climate change has significantly impacted wetlands, which serve as natural buffers against changing climatic conditions and human activities (Çelekli et al., 2023a; Çelekli and Zariç, 2023b; Zariç et al., 2024). Increased temperatures, erosion, drought, and rising sea levels disrupt wetland ecosystems, threatening the livelihood of species inhabiting them (Çelekli and Zariç, 2023a, 2023c). Among these, algae play a crucial role. Algae constitute a vital component of wetland ecosystems, fulfilling critical functions and some biotechnological applications like removal harmful dyes, plasma technology and terraforming Mars also sustainable construction (Çelekli et al., 2023b, 2024b; Çelekli and Zariç, 2024a, 2024b, 2024c; Zariç et al., 2022; Çelekli et al., 2023)**.** Algae, which include both macro- and microalgae, are abundant sources of bioactive metabolites that hold great potential for incorporation into functional foods (Çelekli and Zariç, 2023d; Matos et al., 2017). Their complex nutritional makeup, which includes vitamins, minerals, proteins, polysaccharides, polyunsaturated fatty acids, and bioactive substances like polyphenols and pigments, highlights their potential to improve the nutraceutical profile of food products. Modern foods also cause health problems for people's jaws. Functional foods are nutritious against this (Zariç et al., 2023). Algae provide a variety of opportunities for food and beverage fortification, ranging from their immunomodulatory effects and antioxidative and anti-inflammatory qualities to their therapeutic potential against a range of pathological conditions (Wells et al., 2017). Aside from improving nutritional fortification, adding algae to functional food formulations encourages the creation of novel, value-added products that cater to changing consumer demands and health requirements (Katiyar and Arora, 2020). Previously recognized as *Spirulina platensis*, *Arthrospira platensis* is a unique microscopic photosynthetic cyanobacterium that is valued for its intricate nutritional composition and possible health advantages (Belay, 2007). According to taxonomy, *A. platensis* belongs to the genus *Arthrospira*. It has filamentous structures made up of cells that are cylindrical arranged in spiral or rectilinear patterns (Papapanagiotou and Gkelis, 2019). Alkaline lakes and regulated outdoor ponds are the primary habitats for *A. platensis*, which prefers conditions high in solar radiation, vital nutrients, and carbon dioxide (Pereira, 2020). For commercial purposes, it is harvested, dried, and packaged for use in animal husbandry, human nutraceutical supplementation, naturally pigmentation, and applications in biotechnology (Belay, 2013). With a mean protein content of 60% and a wide range of preventive and remedial nutrients, such as B-complex vitamins, important minerals, antioxidants, and carotenoids, *Arthrospira platensis* shows great potential as a source of high-quality dietary supplements and nutraceutical blends (Sharoba, 2017). Historically valued for its nutritional value, *Arthrospira platensis* has gained acceptance as a possible staple food from both scientific and regulatory communities (Belay, 2013). Regulatory agencies have endorsed *Arthrospira platensis* as Generally Recognized as Safe (GRAS), indicating it's potential as a potent ingredient for functional food formulations that could improve human health and wellness (Çelekli et al., 2024a). Its importance in biotechnological innovation and the production of functional foods is highlighted by its historical significance and current status as a superfood (Bortolini et al., 2022). Research and development efforts regarding *Arthrospira platensis* are aimed at highlighting its physiological benefits and functional attributes in alimentary applications, in addition to exploring the possibility of using it in the production of fresh living-based products despite the difficulties in preserving its bioactive constituents (Gentscheva et al., 2023).

ISBN NR: 978-625-6283-35-0

Figure 1. Microscopic view of *Arthrospira platensis* (UTEX, 2024)

2. COMPONENTS OF *Arthrospira platensis* AND THEIR SIGNIFICANCE

A. platensis is becoming more and more well-known as a food supplement due to its abundant protein content and nutritional benefits. *A. platensis* nearly 70% of its dry weight is made up of protein, which is also highly nutritious due to the high quantity and quality of amino acids it contains. Table 2 lists all of the essential amino acids that are present in *A. platensis*. Biliproteins, particularly C-phycocyanin, which makes up 20% of all protein fractions, are present in *A. platensis*. The antioxidant property of the C-phycocyanin molecule controls immunity and shields the body from illness (Seyidoglu et al., 2017). The highest dietary source of vitamin A (beta-carotene), vitamin E, thiamin (vitamin B1), biotin (vitamin B7), and inositol (vitamin B8) is found in *A. platensis* (Table 3.). Beta-carotene is essential for antioxidant processes in living things and is present in *A. platensis* in a form biotransformed to humans. Is a rich natural source of phyto pigments, including vitamins A, K, B1, B2, B12, carotenoids, and xanthophyll (Seyidoglu et al., 2017). Even though *A. platensis* has just a few lipids (4–7%), it contains γ-linolenic and linolenic acid, two fatty acids that are vital for humans. γ-linolenic (GLA) is a potent component of nutraceuticals and a polyunsaturated fatty acid. One of the most abundant sources of γ-linolenic acid (GLA)-containing algae is *Arthrospira*. Because these components have precursor effects on prostaglandins and leukotrienes, they also function as immune and cardiovascular mediators (Kulshreshtha et al., 2008). The lipid content of *A. platensis* with its ratios is shown in Table 4. Numerous minerals, including potassium, calcium, chromium, copper, iron, magnesium, manganese, phosphorus, selenium, sodium, and zinc, are found in *A. platensis*. The calcium, iron, and phosphorus includes of this microalgae make it a beneficial component (Ghanbarzadeh et al., 2022). Utilizing *A. platensis* phosphorus and calcium includes has a significant effect on bone calcification and enhances bone health (Walter, 1997). The mineral content and ratios of *A. platensis* are shown in Table 5. *A.platensis* contains 13.6% carbohydrates consisting of glucose, mannose, galactose and xylose. Since it does not contain cellulose, *A.platensis* is a safe and easily digestible food item that can be consumed by humans because cellulose is not absorbed by humans (Walter, 1997). Another important feature is the enormous molecular weight polysaccharide molecule isolated from *A.platensis*. Scientific authorities refer to his polysaccharides immunomodulatory agents' effect as "immulina (Nielsen et al., 2010)."

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Table 1. *Arthrospira platensis*, protein content of some microalgae and protein content of other foods.

Food protein origin	Protein (%)	Reference
Arthrospira powder	**63**	(Becker, 2007)
Dunaliella salina	57	(Becker, 2007)
Chlorella vulgaris	51-58	(Becker, 2007)
Scenedesmus obliquus	50–56	(Becker, 2007)
Whole egg	45.21	(Ndife et al., 2010)
Beer yeast	45	(Henrikson, 1994)
Parmesan cheese	36	(Henrikson, 1994)
Chicken breast meat	21,8	(Arslan, 2013)
Fish	18-22	(Turan et al., 2006)

Table 2. Content of essential amino acids (g/100 g) in dry weight from conventional and microalgal source.

Protein and amino acids	*A.platensis*	*Arthrospira sp.*	*Dunaliella sp.*	*Chlorella sp.*
Protein	57.47	45–70	57	51-58
Tryptophan	0.929	5.3	0.7–1.4	2.1
Threonine	2.97	4.6–6.2	1.5–2.8	4.7–4.8
Isoleucine	3.209	6.0–6.7	1.9–2.8	3.8–6.7
Leucine	4.947	8.0–9.8	3.9–5.7	8.8–9.2
Lysine	3.025	4.6–4.8	2.4–2.7	8.4–8.9
Methionine	1.149	1.4–2.5	0.8–1.0	2.2
Phenylalanine	2.777	4.9–5.3	2.5–2.8	5
Valine	3.512	6.5–7.1	2.0–2.9	5.5–6.1
Arginine	4.147	7.3	3.0–7.3	6.4
Histidine	1.085	2.2	0.8–1.8	2.0
Reference	(Seyidoglu et al., 2017)	(Becker, 2007; Hosseinkhani et al., 2022; Panlasigui et al., 2021)	(Becker, 2007; Gibbs and Duffus, 1976)	(Becker, 2007; Hosseinkhani et al., 2022; Sidari and Tofalo, 2019)

Table 3. Vitamins in *Arthrospira platensis* powder (Belay, 1997).

Vitamins	mg/100g
Provitamin A equiv.	**2.330 × 103 IU/kg**
Vitamin E d-a-tocopherol	5
Thiamin B1	**3.5**
Riboflavin B2	**4.0**
Niacin B3	14
Vitamin B6 pyridoxine	**0.8**
Vitamin B12 cobalamin	**0.32**
Folic acid	0.01
Biotin	0.005

Phantothenic acid	0.1
Vitamin K	**2.2**

Table 4. Fatty acid composition of *Arthrospira platensis* powder (Ötleş and Pire, 2001)

Fatty acids	**(%)**
Myristic acid	0.23
Palmitic acid	46.07
Palmitoleic acid	1.26
Oleic acid	5.26
Linoleic acid	**17.43**
Gamma-Linolenic acid	**8.87**
Others	20.88

Table 5. Minerals in *Arthrospira platensis* powder (Belay, 2007)

Mineral	**mg/100g**
Calcium	700
Chromium	0.28
Copper	1.2
Iron	100
Magnesium	400
Manganese	5
Phosphorus	800
Potassium	1400
Sodium	900
Zinc	3

3. USE OF *Arthrospira platensis* IN FUNCTIONAL FOODS

Due to its rich nutritional makeup and numerous health advantages, *Arthrospira platensis*, also referred to as *Spirulina*, has gained interest as a potential component in the creation of functional foods (Lafarga et al., 2020). It has been observed that when *A.platensis* is added to food matrices such as beverages, chocolate and biscuits, the nutritional profiles of the products increase significantly (Çelekli et al., 2024a). Studies reveal that *A. platensis* adds significant benefits to biscuit (Figure 2.) formulations in terms of flavor and texture as well as protein content, increasing it by up to 57%. This means that biscuits with *A. platensis* are more nutrient-dense choices for people who need daily fortification (Çelekli et al., 2024a; Gün et al., 2022). Research has also shown that cooked foods enhanced with microalgae retain their micronutrient content, seemingly enhancing *A. platensis's* nutritional value without sacrificing its nutritional integrity through heat treatment (Guedes and Malcata, 2012).

Additionally, *A. platensis* shows a great deal of promise for improving gluten-free bread recipes, meeting the needs of people who have celiac disease. Gluten-free bread (Figure 3.) products made from rice flour supplemented with *A. platensis* instead of wheat flour show appreciable increases in protein content (up to 39.04%) and notable enrichments in essential amino acids (leucine, threonine, methionine, and isoleucine). (Çelekli et al., 2024a) These

ISBN NR: 978-625-6283-35-0

developments not only compensate for the nutritional deficits that are frequently linked to gluten-free diets, but they also enhance the palatability of these bread products, increasing their attractiveness to customers following gluten-free protocols (Fradinho et al., 2020). Moreover, cookies enriched with *A. platensis* have better digestibility than cookies without microalgae, which implies that they could be used to treat nutritional deficiencies, especially in undernourished people (Hosseinkhani et al., 2022).

Furthermore, the incorporation of *A. platensis* into fermented dairy products, such as ayran, showcases its potential in augmenting both the nutritional and functional attributes of such food items (Beheshtipour et al., 2013). The growth and vitality of probiotic microorganisms are improved and their probiotic potential and nutritional value are increased when *A. platensis* is added to probiotic-fermented milk products (Figure 4) (Çelekli et al., 2020). This symbiotic relationship enhances the nutritional profile of ayran and highlights its probiotic effectiveness, providing consumers with a convenient and health-promoting beverage option (Çelekli et al., 2020). All things considered, the various ways that *A. platensis* is used in functional food recipes highlight how important it is as a nutrient-dense, sustainable ingredient that can help with a range of dietary needs and promote overall health (Birch and Bonwick, 2019).

Figure 2. *A. platensis* added biscuit (Gün et al., 2022).

Figure 3. Gluten-free bread made from rice flour with *A.platensis* added instead of wheat flour (Zlateva and Chochkov, 2019).

ISBN NR: 978-625-6283-35-0

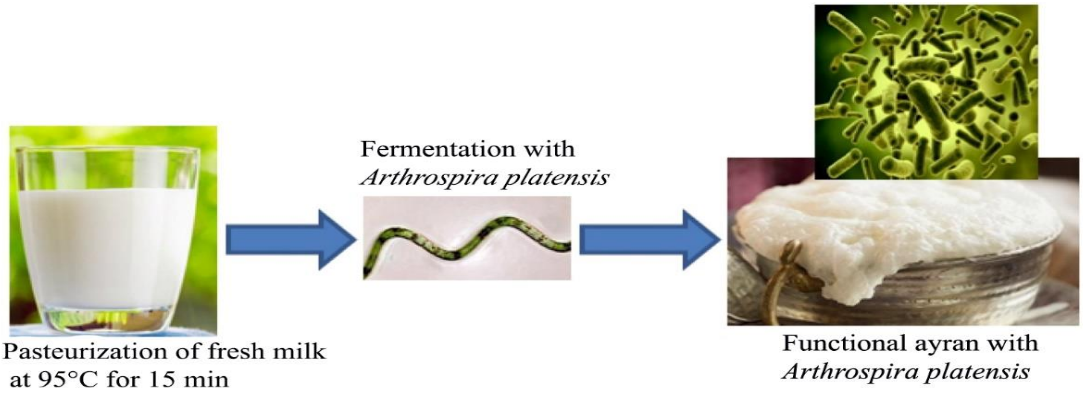

Figure 4. Ayran with fortified content by adding A. *platensis* (Çelekli et al., 2019)

4. ADVANTAGES OF USING *Arthrospira platensis* IN FUNCTIONAL FOOD

In the past thirty years, there has been a notable growth and change in the field of microalgal biotechnology, primarily due to the increased understanding and application of species of microalgae like *Arthrospira platensis* (Udayan et al., 2021). A. *platensis* has historically been a part of the diets of indigenous populations for centuries, both in Mexico and Africa, demonstrating its nutritional value and long-standing cultural significance (Çelekli et al., 2024a). A. *platensis* stands out for its exceptional nutrient density, boasting a rich composition of proteins, vitamins (particularly B vitamins like B12), minerals (such as iron, calcium, and magnesium), essential fatty acids, and antioxidants like phycocyanin and beta carotene (Guasto et al., 2018). There is a noticeable improvement in the nutritional profile and related health benefits of functional foods when A. *platensis* is included (Ampofo and Abbey, 2022).

Moreover, *A. platensis*'s antioxidant qualities, which are linked to substances like beta-carotene, phycocyanin, and tocopherol, have the potential to significantly reduce the symptoms of oxidative stress-related illnesses and chronic conditions (Abdel-Latif et al., 2022). By consuming functional foods enhanced with A. *platensis*, people can increase their intake of antioxidants, which will help them stay healthy overall (Figure 5.) and resist damage from oxidative stress (Seyidoglu et al., 2017). Additionally, studies highlight the significance of A. *platensis* in cholesterol regulation, with data indicating that it can both raise HDL and decrease LDL cholesterol, promoting cardiovascular health (Deng and Chow, 2010). The incorporation of A. *platensis* into functional foods aimed at regulating cholesterol levels may provide supplementary health advantages, enhancing the preventive and treatment approaches against cardiovascular disorders (Pina-Pérez et al., 2019).

Furthermore, the fact that international organizations have acknowledged A. *platensis* highlights its potential as a nutritional powerhouse with far-reaching effects (AlFadhly et al., 2022). A. *platensis* is a valuable food source that has been recognized by the World Health Organization as a significant solution to malnutrition. It is a promising plant for addressing issues related to global food security (Seyidoglu et al., 2017). Due to its high growth rate, low cultivation requirements, and exceptional nutrient content, A. *platensis* is a promising option for sustainable food production projects, especially in areas with limited resources (Ahmad and Ashraf, 2023). Regulatory organizations like the National Institutes of Health have also taken an interest in A. *platensis* due to its potential therapeutic uses in immune system dysfunction, nervous system disorders, and metabolic diseases like diabetes and high cholesterol (Gentscheva et al., 2023).

The idea of "functional foods," which first gained popularity in Japan in the 1980s, has spread throughout the world due to consumer demand for goods that provide health benefits above and beyond mere nourishment (Birch and Bonwick, 2019). Food science and nutrition are about to enter a new era marked by the rise of functional foods as a separate food category, with A. *platensis* expected to play a significant role in this development (Pina-Pérez et al., 2019). While scientific substantiation of *Arthrospira*'s health benefits is paramount for the development of specific functional products, its potential as a therapeutic agent against conditions like diabetes, hyperlipidemia, oxidative stress-induced diseases, and cancer underscores its relevance in contemporary food science and nutrition (De la Jara et al., 2018). The FDA in the US and the Ministry of Health and Welfare in Japan are two examples of regulatory frameworks that govern functional foods in different regions. These frameworks highlight the need for rigorous scientific inquiry in the development of functional food products and emphasize the significance of scientific validation in supporting health claims associated with bioactive ingredients like *Arthrospira* (Camacho et al., 2019).

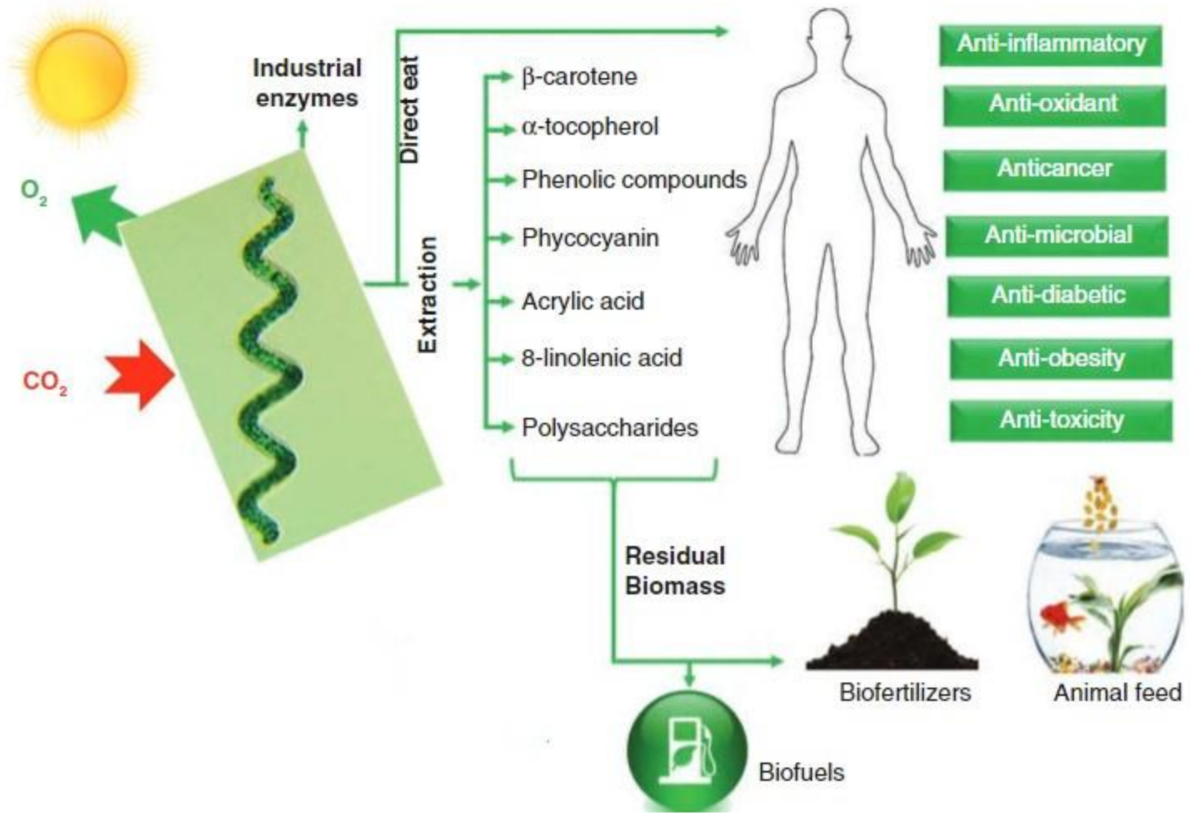

Figure 5. Advantages of *A. platensis* (Shao et al., 2019).

5. CONCLUSIONS

In conclusion, *Arthrospira platensis*, shows promise as a solution to today's dietary problems and as a way to further the development of functional foods. *A. platensis* provides a wealth of health benefits due to its rich nutritional profile, which includes essential amino acids, antioxidants, vitamins, minerals, high-quality proteins, and essential fatty acids. Its anti-oxidant qualities aid in the fight against diseases linked to oxidative stress, and its hypocholesterolemic qualities enhance cardiovascular health. It is also a useful tool in the fight against global food insecurity because of its capacity to combat malnutrition and provide a sustainable food source.

We can meet consumer demands for health-promoting options while simultaneously improving the nutritional value of a variety of products by incorporating *A. platensis* into functional food formulations. With its therapeutic potential still being unearthed, *A. platensis* has the potential to significantly impact food science and nutrition in the future by helping to create functional foods that not only support but also nourish overall health and wellness.

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