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# RESEARCH ON THE NUTRITIONAL VALUE, BIOACTIVE COMPOUNDS CONTENT AND ANTIOXIDANT CAPACITY OF SPIRULINA

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***Abstract***

*Spirulina is a blue-green microalga, rich in bioactive compounds and nutrients. The high nutritional value and therapeutic potential of Spirulina have increased its global importance and the demand to make healthy food products fortified with this microalgae.The aim of this work was to determine the nutritional value, bioactive compounds and antioxidant capacity of Spirulina. The analyzed Spirulina samples stand out for their protein content (62.49-66.17%), total fiber (5.92-8.86%), total ash (6.22 -10.47%), vitamins (vitamin C: 55.45-82.73 mg/100 g; vitamin B1: 0.627-1.08 mg/100 g; vitamin B2: 2.12-3.84 mg/100 g; vitamin B3 (Niacin): 8.21- 12.83 mg/100 g; vitamin B5: 2.15-3.05 mg/100 g; vitamin B6: 0.653-0.875 mg/100 g; vitamin B9: 0.327-0.588 mg/100 g; vitamin B12: 0.105-0.127 mg/100 g ), total polyphenols 154.50 -256.26 mg GAE/100 g), mineral elements (Na:85.77-120.45 mg/100 g; K:1385.37-1678.72 mg/1100 g; Ca: 850-1185.57 mg/100 g; Mg: 205.34-248.93 mg/100 g; Fe: 21.32-46.58 mg/100 g; Zn: 1.23-1.85 mg/100 g). Due to its high antioxidant content, Spirulina has antioxidant capacity (5.42-9.12 micromol Trolox/g). Due to its complex biochemical composition, Spirulina powder has antioxidant and therapeutic potential and can also be used for food fortification.*

***Key words**: Spirulina, microalgae, nutrients, bioactive compounds, antioxidant capacity.*

## INTRODUCTION

The exponential growth of the human population, climate change, water scarcity and the decrease of agricultural land constitute the global problems of society and a challenge for the production of food for the next generations. Given the exponential growth of the population and considering that several million tons of food are lost each year at various stages of the food chain, including production, post-harvest, processing and distribution, in the year 2050 will be necessary an increase of 50-60% of food production to feed everyone (Pereira et al., 2022). Microalgae have several attractive features for sustainable production at large scale, such as high biomass yields per unit area and the ability to be cultivated on non-arable land using non-potable water, or even salt water (Torres-Tiji et al., 2020).
Microalgae can be used as alternative foods with high nutritional value (Prihanto et al., 2022). *Spirulina* is a green-blue microalga, rich in bioactive compounds and nutrients (Shaban et al., 2017). *Spirulina* has been used both as a food and as a supplement (Moejes and Moejes, 2017).
*Spirulina* is produced in 23 countries, but the largest amounts of biomass are produced in Norway, France and Ireland (Araújo et al., 2021). *Spirulina* is of real interest for the food industry, due to its high content in proteins, minerals, vitamins, antioxidant carotenoid pigments and fatty acids and its high antioxidant capacity: proteins (35.4-70 g/100 g), fats (4-16g/100 g ), carbohydrates (14-19 g/100 g), crude fiber (3-7g/100 g), mineral elements (Potassium: 2.0-2.6 g/100 g; Sodium: 1.5-2.2 g/100 g ; Phosphorus: 1.3-2.2 g/100 g; Iron: 273.2-787.0 mg/kg; Magnesium: 330 mg/100 g; Calcium: 120-900 mg/100 g), water-soluble vitamins (C: 115.03 mg/100 g; B12: 5.7-38.5 $\mu$g/100 g; B2: 3.0-4.6 mg/100 g; B6: 0.5-0.8 mg/100 g; B3 13-15 mg /100 g; B9: 0.05-9.92 mg/100 g); carotenoids (0.3-2.6 g/100 g), total phenolic compounds (0.20-1.73 g/100 g), polysaccharides (0.2-12.5 g/

100 g) (Ragaza et al., 2020; Rahim et al., 2021; Bensehaila et al., 2015).

The aim of this work was to determine the nutritional value, bioactive compounds and antioxidant capacity of *Spirulina.*

Also, *Spirulina* stands out for its fatty acid content. Mahardika et al. (2022), reported in the case of *Spirulina*, the following profile of fatty acids: 33.78% saturated fatty acids (such as docosanoic acid, octadecanoic acid, hexadecanoic acid and hexanedioic acid), 35.82% unsaturated fatty acids (fatty acids monounsaturated, diunsaturated fatty acids, triunsaturated fatty acids). The same authors showed in the research undertaken, that in the case of Spirulina, palmitic acid (hexadecanoic acid) has the highest content (25.21%).

Due to the complex biochemical composition, *Spirulina* and food products fortified with *Spirulina* have strong therapeutic effects in many conditions caused by oxidative damage such as neurodegenerative diseases, tumors, inflammation, immunosenescence, toxicosis, various internal organ damage, cardiovascular diseases, obesity, diabetes, etc. indicating enormous application potential in medicine and health (Han et al., 2021; Carrizzo et al., 2019; Huang et al., 2018; Neyrinck, 2017).

The aim of this work was to determine the nutritional value, bioactive compounds and antioxidant capacity of *Spirulina*.

## MATERIALS AND METHODS

### Materials

*Spirulina* samples were purchased from pharmacies (they are imported samples).

Figure 1 shows three *Spirulina* samples taken in the study.

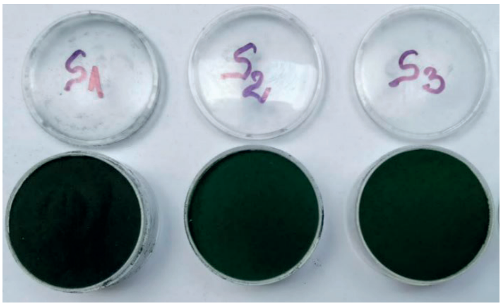


Figure 1. S*pirulina* powder samples

### Methods

***Statistical analysis***

The *Spirulina* samples were analyzed in triplicate, and for each analytical parameter studied, the average value and standard deviation were reported.

***Sensory analysis***

Sensory analysis (appearance, taste, smell) was performed using the descriptive method.

Instrumental analysis of color (L*, a* and b*) was performed with CM-5 colorimeter (Konica Minolta, Japan), using SpectraMagic NX software.

***Physico-chemical analysis***

Moisture was determined by Halogen Moisture Analyzer HE53 (Mettler Toledo).

Chemical indicators have determined using AOAC Methods: 9 79.09 (protein content), 963.15 (fat content), 923.03 (ash content) and AOAC 985.29 (total dietary fiber). Total carbohydrate content (%) was estimated by subtracting water, fat, protein and ash content from 100%. The energy value calculation (kcal/100 g and kJ/100 g) was carried out according to the provisions of Commission Regulation no. 1169/2011 (European Commission, 2011).

Determination of iron, copper, manganese and zinc was performed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS, model NexION300Q, Perkin Elmer) after dry digestion of the samples. The determination of sodium, potassium, calcium and magnesium was carried out by High-Resolution Continuum Source Atomic Absorption Spectrometry (Analytik Jena, model contrAA 700 - High-Resolution Continuum Source Atomic Absorption Spectrometer), flame technique, after dry digestion of the samples.

***Bioactive compounds content***

Total polyphenol content was performed by Folin-Ciocalteau spectrophotometric method, according to Horszwald and Andlauer (2011), with some modifications, using UV-VIS Jasco V 550 spectrophotometer, at wavelength λ = 755 nm. The quantification of the total polyphenol content was based on the calibration curve of gallic acid (0-0.20 mg/mL).

The determination of the content in C and B vitamins was carried out by liquid chromatography (Accela chromatograph, Thermo Scientific) coupled with high-resolution mass spectrometry (LTQ Orbitrap XL Hybrid Ion Trap-Orbitrap Mass Spectrometer, Thermo Scientific) (Asănică et al., 2019).

***Antioxidant capacity***

Antioxidant capacity was performed by DPPH (1,1diphenyl-2-picryl hydrazyl) method, according to Horszwald and Andlauer (2011), using UV-VIS Jasco V 550 spectrophotometer, at wavelenght λ = 517 nm and calibration curve of Trolox ( 0-0.4375 mmol/L).

***Microbiological analysis***

The microbiological indicators were determined using the following methods: SR ISO 21527-1:2009 (Yeasts and molds), SR EN ISO 21528-1:2017 method (*Enterobacteriaceae*), SR ISO 16649-2:2007 (*Escherichia coli*), SR EN ISO 6579-1:2017 (*Salmonella*), ISO 21807:2004 (Water activity). Water activity was determined using Aquaspector AQS 31 equipment.

## RESULTS AND DISCUSSIONS

### Sensory analysis

The sensory analysis revealed that *Spirulina* is presented in the form of a dark green powder and has a specific taste and smell.

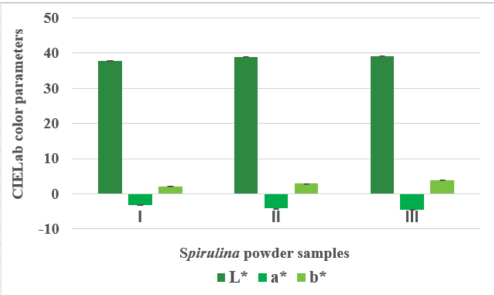


Figure 2. Colour parameters of *Spirulina* powder

Following the instrumental analysis of the color (Figure 2), it was found that the green powders obtained from cauliflower leaves had negative values of the a* parameter (-4.46...-3.14), positive values of the b* parameter (2.20... .3.86) and low luminance values (37.83...39.10).

The luminance values (L*) recorded in the case of the *Spirulina* powders in this study are higher than that reported by Demarco et al. (2022), in the case of *Spirulina* powder obtained through various dehydration processes (air drying, cast-tape drying, freeze-drying, vacuum cast-tape drying) from raw biomass of *Spirulina*: 13.09-20.30. The values of parameter a* (red-green color) and parameter b* fall within the ranges specified by Demarco et al. (2022), for these parameters, in the case of *Spirulina* powder (a*: -13.11...-3.76; b*: 1.64...10.88).

### Physico-chemical analysis

The physico-chemical indicators of the *Spirulina* powder are presented in Table 1.

The *Spirulina* powders stand out for their content in protein (62.49-66.17%), ash (6.22-10.47%), carbohydrates (7.94-9.25%) and total fiber (5.92-8.86%).

Table 1. The physico-chemical indicators of *Spirulina* powder

| Physico-chemical indicators | *Spirulina* powders | | |
|---|---|---|---|
| | Sample I | Sample II | Sample III |
| Moisture (%) | 7.13±0.18 | 5.90±0.15 | 8.73±0.22 |
| Ash (%) | 6.22±0.09 | 6.34±0.09 | 10.47±0.16 |
| Protein (%) | 64.18±0.96 | 66.17±0.99 | 62.49±0.94 |
| Fat (%) | 4.53±0.06 | 5.78±0.08 | 3.14±0.04 |
| Total fiber (%) | 8.86±0.16 | 7.87±0.15 | 5.92±0.11 |
| Carbohydrates (%) | 9.08±0.06 | 7.94±0.05 | 9.25±0.06 |
| Energy value (kcal/100g) | 316 | 333 | 303 |
| Energy value (kJ/100g) | 1333 | 1402 | 1282 |

The moisture content of *Spirulina* powder in this study is in the range reported by other authors: 5.81-10.1 % (Koli et al., 2022; Raczyk et al., 2022; Ali, 2022; Matos et al., 2016). It is important to ensure a maximum humidity of 10.5%, in the case of *Spirulina* powder, to ensure the microbiological stability of this microalgae.

Ash is an important chemical indicator that, in the case of the studied *Spirulina* powders, varied in the range of 6.22-10.47% (the minimum value was recorded in the case of Sample I, and the maximum value in the case of Sample III).

The ash content of these *Spirulina* samples is higher compared to those reported by Raczyk et al. (2022) (Ash content = 5.93%) and Saharan and Jood (2017) (Ash content = 3.5%). Sample III of *Spirulina* powder has the highest ash content, compared to the other two analyzed samples and, at the same time, higher than those reported by Koli et al. (2022) (Ash content = 8.34%) and Tańska et al. (2017) (Ash content = 7.90%).

The protein content of *Spirulina* powder taken in the study is higher compared to those reported by Ali (2022) (Protein content = 56.2%), Lafarga et al. (2020) (Protein content = 57.5 %), comparable to that reported by Koli et al. (2022) (Protein content = 65.71%), but lower than those reported by Raczyk et al. (2022) (Protein content = 71.34%), Saharan and Jood (2017) (Protein content = 71.90%). *Spirulina* is the richest natural source of digestible protein that provides all essential amino acids to the human body (Guil-Guerrero et al., 2004).

High digestibility of *Spirulina* is due to the fact that its cell wall is made up of 86% from digestible polysaccharides (Li and Qi, 1997). Also, it is worth emphasizing that the total nucleic acid content of *Spirulina* is in the range of 4.2-6% d.m. and does not present any risk of increasing plasma uric acid when consuming up to 10 g/day (Soni et al., 2020). Capelli and Cysewski (2010) mention that *Spirulina* contains protein as high as 670% compared to tofu. In many countries in Africa, *Spirulina* is still used as human food because it is a major source of protein, and thus, it is collected from natural water, dried and consumed. Today, *Spirulina* is used in many countries as a disease prevention strategy to maintain health (Koli et al., 2022). The consumption of *Spirulina* lead to a series of beneficial health effects, having immunomodulatory, antioxidant, anticancer, antiviral and antibacterial properties. At the same time, the consumption of *Spirulina* have positive effects against malnutrition, anemia, hyperlipidemia, diabetes, obesity, inflammatory allergic reactions, toxicity induced by heavy metals (Wu et al., 2016).

The lipid content of the analyzed *Spirulina* powders varied between 3.14-5.78%, being higher than those reported by other authors: Raczyk et al., 2022 (Fat content = 0.36%) and Saharan and Jood, 2017 (Fat content = 1.27%). The main fatty acids contained in *Spirulina* are gamma-linolenic acid, linoleic acid and palmitic acid (Esquivel-Hernández et al., 2016). Among these fatty acids, gamma-linolenic acid is known to be a functional compound of *Spirulina* lipids, along with carotenoids, tocopherols and sterols, because there are not many food sources that contain a significant content of gamma-linolenic acid (Esquivel-Hernández et al., 2016; 2017; Gutiérrez-Salmeán et al., 2015; Ku et al., 2013). At the same time, gamma-linolenic acid is the precursor of prostaglandins, leukotrienes and thromboxanes that are mediators in inflammatory processes, in immune processes, participating in the prevention of several chronic inflammatory diseases and cancers (Das, 2004; Gutiérrez-Salmeán et al., 2015; Sergeant et al., 2016)

The total fiber content of the *Spirulina* powders taken in the study varied in the range: 5.92-8.86 % (the minimum value was recorded in the case of Sample III, and the maximum value in the case of Sample I). Raczyk et al. (2022) reported in the case of *Spirulina* powder a total fiber content of 8.45%. Also, in the case of *Spirulina* powder, Morsy et al. (2014) report a fiber content of 7.93%, and Saharan and Jood (2017), reported a fiber content of 14.98%. Fiber consumption has beneficial effects on the human body (lowering cholesterol levels, helping to control sugar levels and maintaining gut health), it is beneficial to enrich our diet with fiber (Ötles, and Ozgoz, 2014; Fuller et al., 2016).

The carbohydrate content of the *Spirulina* powders analyzed in this study varied between 7.94-9.25 (the minimum value was recorded in the case of Sample II, and the maximum value in the case of Sample III). The carbohydrate content of these *Spirulina* samples is higher than that reported by Raczyk et al. (2022) (Carbohydrates content = 6.83 %), but lower than those reported by Koli et al. (2022) (Carbohydrates content = 21.87%) and Saharan and Sudesh (2017) (Carbohydrates content = 13.63%). *Chlorella vulgaris* and *Spirulina* produce sulfated polysaccharides that are considered nutraceuticals, being recommended in the prevention and/or treatment of cancer (Carbone et al., 2021; Kiran et al., 2021).

The chemical composition of *Spirulina* powder can vary due to environmental conditions, water composition, climate and salinity (Ali, 2022).

The energy value of the *Spirulina* powders studied is comparable to that reported by Raczyk et al. (2022), in the case of this

microalgae (333.4 kcal/100 g, respectively 1395.0 kJ/100 g).
The *Spirulina* powders are notable for their content in mineral elements (Na, K, Ca, Mg, Fe, Zn, Cu and Mn), which is presented in Figures 3, 4 and 5.
Among the mineral elements, in the case of *Spirulina* powders, potassium has the highest content, in the range of 1385.37-1678.72 mg/100 g (the minimum value was recorded in the case of sample I, and the maximum value in sample III).

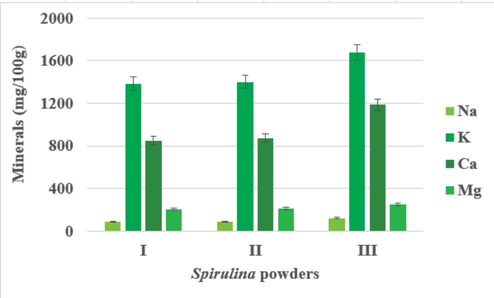


Figure 3. Mineral content (Na, K, Ca, and Mg) of the *Spirulina* powder

The potassium content of *Spirulina* powders (sample I and sample II) is comparable to that reported by Lafarga et al. (2020) in the case of this microalga. Sample III has a higher potassium content than that reported by these authors.
The sodium content of *Spirulina* powder analyzed in the study undertaken (85.77-120.45 mg/100g) is significantly lower than that reported by Lafarga et al. (2020), in the case of this microalga.
*Spirulina* is a microalga recognized for its high level of calcium, which can be used as an alternative source of calcium. The highest calcium content is recorded in the case of *Spirulina* cultivated with sea water (Ekantari et al., 2017). *Spirulina* powders analyzed in our study had a calcium content in the range of 850-1185.57 mg/100 g, the highest value being registered in the case of sample III. The calcium content of *Spirulina* samples from our study is 7.88-11 times more than that reported by Koli et al., 2022 (107.83 mg/100 g) and, respectively, 1.37-1.91 times more compared to that reported by Saharan and Jood, 2017 (620.80 mg/100 g). At the same time, the calcium content of these samples is comparable to that reported by Sharoba (2014), in the case of *Spirulina* powder: 922,278 mg/100 g. Ekantari et al. (2017) conducted a study in which they demonstrated that the bioavailability of calcium from *Spirulina* is higher than that from milk and calcium carbonate. As well, Capelli and Cysewski (2010) mention the fact that *Spirulina* contains calcium as high as 180% compared to milk.
The magnesium content of *Spirulina* powder in our study (205.34-248.93 mg/100 g) is higher than that reported by Lafarga et al. (2020), in the case of the same microalgae: 195 mg/100 g.
*Spirulina* powder is an important source of iron. The iron content of the studied *Spirulina* (Figure 4) was in the range of 21.32-46.58 mg/100 g, the highest content being recorded in the case of sample III.

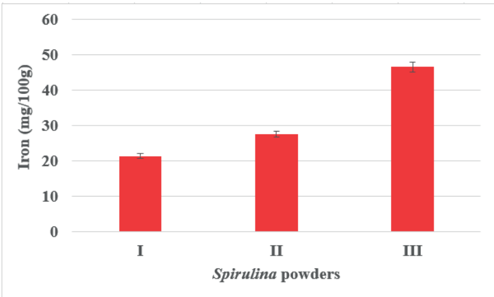


Figure 4. Iron content of the *Spirulina* powder

The iron content of samples I and II is comparable to that reported in the case of *Spirulina* powder by Lafarga et al., 2020 (28.5 mg/100 g) and Koli et al., 2020 (26.59 mg/ 100 g), respectively. The iron content of sample III is 1.63 times and 1.75 times higher, respectively, than that reported by the authors mentioned above, in the case of *Spirulina* powder. Capelli and Cysewski (2010) mention that *Spirulina* contains iron as high as 5100% compared to spinach. *Spirulina* is an important source of iron containing 20 times more iron than a gram of wheat. Iron is a mineral that is mainly present in foods of animal origin such as meat and fish (Balasubramani et al., 2016). Consuming *Spirulina* is very beneficial especially for athletes, vegetarians, pregnant women and teenagers (Soni et al., 2017). Selmi et al. (2011) showed that supplementing the diet with *Spirulina* increases hemoglobin levels and improves the immune system in the elderly.

The zinc content of the analyzed *Spirulina* powder (1.23-1.85 mg/100 g) is lower than that reported by Lafarga et al., 2020 (2.0 mg/100 g). The zinc content of sample III is comparable to that reported by Koli et al., 2022 (1.87 mg/100 g).

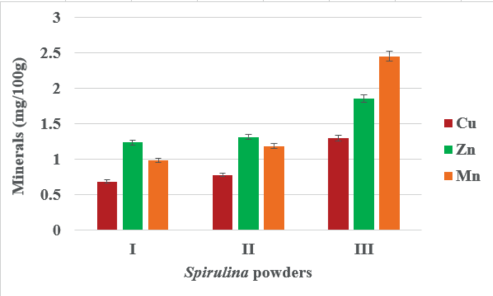


Figure 5. Mineral content (Zn, Cu and Mn) of the *Spirulina* powder

The copper content of the *Spirulina* powder samples taken in the study is comparable to that reported by Sharoba (2014) (1.2154 mg/100 g), but 4.73-8.9 times lower compared to that reported by Lafarga et al., 2020 (6.1 mg/100 g). The manganese content of the three *Spirulina* powder samples varied in the range of 0.98-2.45 mg/100 g, being comparable to that reported by Lafarga et al. (2020) (1.9 mg/100 g)

## Bioactive compounds content

The *Spirulina* powders stand out for their content in bioactive compounds: total polyphenols, vitamin C, B group vitamins, β-Carotene and lutein. The content in bioactive compounds of the *Spirulina* powders is presented in Table 2.

Table 2. Bioactive compounds content of the *Spirulina* powder

| Bioactive compounds | *Spirulina* powders | | |
|---|---|---|---|
| | Sample I | Sample II | Sample III |
| Total polyphenols (mg GAE/g) | 154.50±3.86 | 223.74±5.59 | 256.26±6.41 |
| Vitamin C (mg/100g) | 55.45±1.66 | 61.84±1.85 | 82.73±2.48 |
| Vitamin B1(mg/100g) | 0.627±0.019 | 0.745±0.022 | 1.08±0.032 |
| Vitamin B2 (mg/100g) | 2.12±0.06 | 2.23±0.07 | 3.84±0.12 |
| Vitamin B3 (Niacin) (mg/100g) | 8.21±0.25 | 9.12±0.27 | 12.83±0.38 |
| Vitamin B5 (mg/100g) | 2.15±0.06 | 2.42±0.07 | 3.05±0.09 |
| Vitamin B6 (mg/100g) | 0.653±0.020 | 0.687±0.021 | 0.875±0.026 |
| Vitamin B9 (mg/100g) | 0.327±0.010 | 0.346±0.010 | 0.588±0.017 |
| Vitamin B12 (mg/100g) | 0.105±0.003 | 0.112±0.003 | 0.127±0.004 |
| β-carotene (mg/100g) | 185.21±4.26 | 201.64±4.64 | 325,45±7.48 |
| Lutein (mg/100g) | 10.67±0.25 | 12.32±0.28 | 15.85±0.36 |

The total polyphenol content of *Spirulina* powders varied in the range of 154.50 – 256.26 mg GAE/100g, being higher than that reported in 2017 by Kuatrakul et al., were in the case of *Spirulina* powder obtained by hot air dehydration of fresh *Spirulina*: 99.76 mg GAE/100 g d.m. Also, the total polyphenol content of sample III is comparable to that reported by Kuatrakul et al., 2017, in the case of *Spirulina* powder obtained by microwave dehydration of fresh *Spirulina*: 273.26 mg GAE/100 g d.m. The content of total polyphenols of *Spirulina* powder analyzed in the study is lower than that reported by other authors in the case of *Spirulina*: 408 mg GAE/100 g (Rodríguez De Marco et al., 2014), respectively, 484.2 mg mg GAE/100 g (drying under vacuum at 60°C) and 607.6 mg GAE/100 g (drying at 55°C) (Larrosa et al., 2016). Rose et al. (2023) mention the fact that the differences in total polyphenol content, in the case of *Spirulina* powder samples procured from various sources, can be explained by the different stages of maturity and harvesting, respectively processing (such as grinding and drying conditions) of the *Spirulina* used as raw material.

The vitamin C content of the *Spirulina* samples analyzed varied between 55.45-82.73 mg/100 g, and it was lower compared to that reported by Rahim et al. (2021) for this microalgae: 115.03 mg/100 g. The highest vitamin C content was recorded in sample III (87.23 mg/100 g). The vitamin B1 content of the *Spirulina* powder taken in the study varied between 0.627-1.08 mg/100 g, being lower than that reported by Lafarga et al. (2020): 2.4 mg/100 g. The vitamin B2 content from the *Spirulina* samples is higher compared to the vitamin B1 content and varied between 2.12-3.84 mg/100 g. The vitamin B2 content of sample III is comparable to that reported by Lafarga et al., 2020 (3.7 mg/100 g), but lower compared to that reported by Liestianty et al. (2019), in the case of *Spirulina* powder: 5.5 mg/100 g. The vitamin B3 content of the Spirulina III sample is similar to that reported by Lafarga et al., 2020 (12.8 mg/100 g), but lower by 14.67% compared to that reported by Liestianty et al. (2019): 15 mg/100 g. The vitamin B5 content of *Spirulina* powders varied between 2.15-3.05 mg/100 g, being about 10-

15 times higher than that reported by Liestianty et al. (2019): 0.2 mg/100 g.
The vitamin B6 content of *Spirulina* powder in this study (0.653-0.875 mg/100 g) is higher than that reported by Lafarga et al. 2020 (0.4 mg/100 g), but it is comparable to that reported by Liestianty et al. (2019), in the case of this microalgae: 0.8 mg/100 g.
The vitamin B9 content of the *Spirulina* samples taken in the study was in the range of 0.327-0.588 mg/100 g, being 4.6-8.3 times higher than that reported by Liestianty et al., 2019 (0.071 mg/100 g), but lower than that reported by Rahim et al. (2021), for *Spirulina*: 0.799 mg/100 g. The vitamin B12 content of the analyzed *Spirulina* samples was within a narrow range (0.105-0.127 mg/100 g), being lower than that reported by Sharoba et al., 2014 (0.175 mg/100g) and respectively Liestianty et al., 2019: 0.360 mg/100g. Soni et al. (2017) mention that dehydration processes of *Spirulina* biomass influence the retention of nutrients and bioactive compounds in *Spirulina* powder.
Thus, the different values recorded for the water-soluble vitamin content of this microalga could be explained.
*Spirulina* powder is an important source of β-carotene. In the case of *Spirulina* powder from this study, the β-carotene content varied between 185.21-325.45 mg/100g, being higher than that reported by Ljubic et al., 2018, (174 mg/100g d.m.), respectively, that reported by Hynstova et al., 2018 (86.85-103.71mg/100g), in the case of this microalgae. Sharoba (2014) reported for β-carotene content a value of 252.7 mg/100g, comparable to that obtained in this study.
Other carotenoids identified in *Spirulina*, but in lower concentrations, include canthaxanthin and lutein (Hynstova et al., 2018). In the case of the analyzed *Spirulina* samples, the lutein content was in the range of 10.67-15.85 mg/100g, being comparable to the minimum value of the range reported by Hynstova et al., 2018, in the case of *Spirulina*: 11.78-103.09 mg/100 g.
Cerón-García et al. (2018) mention that natural carotenoids are preferred compared to synthetic ones, as they are a mixture of trans and cis isomers. Synthetic carotenoids are usually all-trans isomers.

**Antioxidant capacity**
Due to the high content in antioxidants, *Spirulina* powder taken in the study, shows antioxidant activity. Their antioxidant activity varied between 5.42-9.12 µmol TE/g (the minimum value was recorded in sample I, and the maximum value in sample III) (Figure 6).

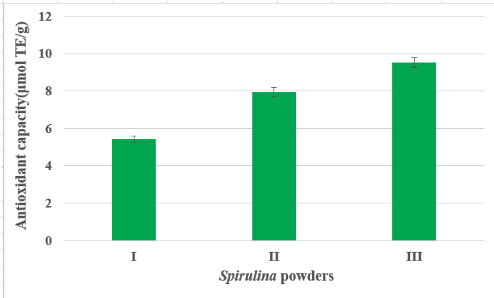


Figure 6. Antioxidant capacity of the *Spirulina* powder

For the *Spirulina* powders between the total polyphenol content and antioxidant capacity it is a linear correlation ($y = 0.0397x - 0.7674$; $R^2 = 0.995$).

**Microbiological analysis**
The microbiological indicators of *Spirulina* powders are presented in Table 3.

Table 3. Microbiological analysis of the *Spirulina* powder

| Microbiological indicators | *Spirulina* powders | | |
|---|---|---|---|
| | **Sample I** | **Sample II** | **Sample III** |
| Yeasts and molds (CFU/g) | < 10 | < 10 | < 10 |
| *Enterobacteriaceae* (CFU/g) | < 10 | < 10 | < 10 |
| *Escherichia coli* (CFU/g) | < 10 | < 10 | < 10 |
| *Salmonella* (in 25 g) | absent | absent | absent |
| Water activity | 0.285 | 0.263 | 0.301 |

The results of the microbiological analysis confirmed the fact that these powders fall within the provisions of the legislation in force. At the same time, it is worth noting that the *Spirulina* powders have low values for water activity (0.285-0.301), which ensures their stability from a qualitative point of view.

## CONCLUSIONS

*Spirulina* is a valuable biological resource, due to its high content in nutrients and bioactive compounds, which give its antioxidant capacity. The *Spirulina* studied stands out for its content in protein (62.49-66.17%), ash

(6.22-10.47%), carbohydrates (7.94-9.25%) and total fiber (5.92-8.86%). It is also worth noting the high mineral content of this microalgae (potassium 1385.37-1678.72 mg/100; calcium: 850-1185.57 mg/100 g; magnesium: 205.34-248.93 mg/100 g; sodium: 85.77-120.45 mg/100 g; iron: 21.32-46.58 mg/100 g; zinc: 1.23-1.85 mg/100 g; manganese: 0.98-2.45 mg/100 g; copper: 0.68-1.29 mg/100 g).

Also, *Spirulina* powder is a source of bioactive compounds: total polyphenols (154.50 – 256.26 mg GAE/100g), vitamin C (55.45-87.23 mg/100g), vitamin B1 (0.627-1.08 mg/100 g) vitamin B2-3 (100 g ) mg/100 g), vitamin B3 (8.21-12.83 mg/100 g), B5 (2.15-3.05 mg/ 100 g), β-Carotene (185.21-325.47 mg/100 g) , lutein (10.67-15.85 mg/100 g).

Due to the high antioxidant content, *Spirulina* powder showed antioxidant capacity (5.42-9.12 μmol TE/g).

The microbiological analyzes carried out have highlighted that *Spirulina* powders comply with the legislation in force and are safe for human consumption.

Being an important source of nutrients and bioactive compounds *Spirulina* powder can be used in the fortification process of food products in order to increase their nutritional value and potential.

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