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RESEARCH ON THE CAPITALIZATION OF THE NUTRITIONAL AND BIOACTIVE POTENTIAL OF CAULIFLOWER LEAVES IN THE CIRCULAR ECONOMY CONTEXT

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Abstract

Globally, it is estimated that a third of all food produced is lost. This is driven by many different factors, but the lack of consumer awareness of the nutritional value and antioxidant potential of certain parts of the food, namely peels, seeds, stems is certainly among them. The objective of this work was to capitalize on the nutritional and bioactive potential of cauliflower waste (leaves), in order to obtain a functional ingredient with high nutritional value and antioxidant potential. This functional ingredient is presented in the form of a homogeneous, microbiologically stable powder and stands out for its content in protein (28.72-29.95%), ash (10.39-11.23%), glucosinolates (240.23-259.65 mmol/g s.u.) total fiber (25.11-30.45%), vitamin C (76.50-89.44 mg/100g), β-carotene (39.45 -47.21 mg/100g), total phenolic compounds (5.75-6.12 mg GAE/g s.u.), mineral elements (Fe: 40.75-51.15 mg/100g; K: 3865.52-4178.21 mg/100g; Ca: 772.23-812.21 mg/100g: Mg: 120.23-145.85 mg/100g; Zn: 5.45-7.78 mg/100g). Due to the high antioxidant content, the functional ingredient obtained from cauliflower leaves has an antioxidant capacity: 13.36 - 14.2 µmol TE/g. Due to its complex biochemical composition and antioxidant capacity, this functional ingredient from cauliflower leaves can be used in the food fortification process.

Key words: *cauliflower, leaves, functional ingredient, antioxidant capacity.*

INTRODUCTION

According to estimations of the UN organization, the world population will reach 9.8 billion by 2050, almost 20% higher than today (U.N.D.E. and S.A., 2019). The exponential growth of the human population, climate change, water scarcity and the decrease of agricultural areas are the global problems of society and a challenge for the production of food for the next generations. Globally, it is estimated that a third of all food produced is lost. This is due to several factors, but the lack of consumer awareness of the nutritional value and antioxidant potential of certain food parts, such as peels, seeds, stems, leaves, is certainly among them (Pereira et al. , 2022).

Plant by-products represent more than a third of all food waste (Bharat Helkar and Sahoo, 2016). In the case of Brassica species, a high percentage of waste results: 45-60% in the case of cauliflower and 60-75% in the case of broccoli (Khedkar et al., 2017; Petkowicz and Williams, 2020; Castelãdo-Baptista et al., 2021). Research undertaken internationally (Drabińska et al., 2021) highlights the fact that cauliflower waste (stems and leaves) are sources of nutrients and bioactive compounds, which can be exploited. Thus, from the results of the research undertaken by these authors, it is highlighted that cauliflower leaves and stems have a content in glucosinolates, phenolic compounds, mineral elements, total amino acids, fibers, higher than cauliflower (inflorescence). At the same time, cauliflower leaves have a higher antioxidant capacity than the inflorescence (leaves: 150 µmol Trolox Equivalents/g d.m.; inflorescence: 133.75 µmol Trolox Equivalents/g d.m.), due to the higher content in bioactive compounds (Drabińska et al., 2021).

International epidemiological studies have highlighted the anticancer effects of isothiocyanates, which are biologically active molecules derived from the enzymatic degradation of glucosinolates (Arumugam and Razis, 2018).

At the same time, cauliflower leaves are a rich source of β carotene, iron and calcium and therefore can be used in the composition of value-added products to treat anemia and nutritional deficiencies (Shivani et al., 2018). Wani and Kaul (2011) showed that dehydrated dried cauliflower leaves are rich in nutrients and are a good source of β carotene (43.11 mg/100 g) iron (60.38 mg/100 g), copper (1.55 mg /100 g), manganese (5.86 mg/100 g), zinc (5.10 mg /100 g). Carotenoids, especially lutein and β-carotene, which are most abundant in *Brassicaceae*, contribute to the reduction of oxidative stress and related disorders such as cancer, diabetes, and cardiovascular diseases (Gul et al., 2015; Jahangir et al., 2009).

It is important to utilize cauliflower waste in functional ingredients with high nutritional value and antioxidant capacity. For this purpose their transformation into powders is of real interest (Salehi, 2020; Santos et al., 2022).

This paper presents the sensory, nutritional, microbiological characteristics, the content in bioactive compounds and the antioxidant capacity of the functional ingredient (powder), obtained by using cauliflower leaves.

MATERIALS AND METHODS

Samples

Cauliflower leaves were procured from Romanian farmers. The experiments undertaken to obtain the functional ingredient (powder) from cauliflower leaves were carried out in the Vegetable-Fruit Processing Pilot Experiment Station, within IBA Bucharest. The technological flow for obtaining this functional ingredient (powder) includes the following operations: sorting, washing, boiling in water at 98-100°C for 2-3 minutes, cutting, dehydration, grinding and packaging.

Dehydration of the plant material was carried out at 50°C, in an electric dryer with forced convection, for 8-9 hours, up to a maximum humidity of 8%. Grinding of the dried plant material was carried out using a Retsch mill, at a temperature of 20-22°C, to ensure the preservation of the nutritional characteristics of the functional ingredient. The functional ingredient obtained from cauliflower leaves was packed in hermetically sealed glass containers and protected with aluminum foil and kept in dry and cool spaces (at a maximum temperature of 20°C), till the sensory, biochemical and microbiological analyses were performed. The Figure 1 show cauliflower leaf powder (three samples).

Figure 1. Cauliflower leaf powder from three different sources (farmers)

Methods

Statistical analysis

The cauliflower leaf powder samples were analyzed in triplicate, and the results obtained for each analytical parameter studied were reported as the average value and standard deviation.

Sensory analysis

Sensory analysis (appearance, taste, smell) was performed using the descriptive method (the method is based on sensory characteristics).

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 were determined using AOAC Methods: 979.09 (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 β-carotene and lutein content was carried out by chromatographic method (High Performance Liquid Chromatograph with Diode array detector) (Catană et al., 2020). The determination of vitamin C content 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) (Catană et al., 2017). The determination of glycosinolate content was carried out using a rapid spectrophotometric method (Mawlong et al., 2017).

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*), ISO 21807:2004 (Water activity). Water activity was determined using Aquaspector AQS 31 equipment.

RESULTS AND DISCUSSIONS

Sensory analysis

Sensory analysis revealed that the functional ingredient obtained by recovery of cauliflower leaves looks like a green powder with a characteristic taste and smell for *Cruciferous* family.

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 (-4.62...-4.55), positive values of the b* parameter (11.42.. .11.74) and low luminance values (48.32...48.55). The luminance values (L*) recorded in the case of the cauliflower leaf powders in this study are higher than the one reported by Drabiańska et al. (2021), in the case of the powder obtained from cauliflower leaves by lyophilization and grinding: L* = 34.24. Also, the value recorded for the a* parameter was higher than that reported by Drabiańska et al. (2021) (a* = -5.13), and the b* parameter registered a lower value than that reported by the same authors: b* = 13.36.

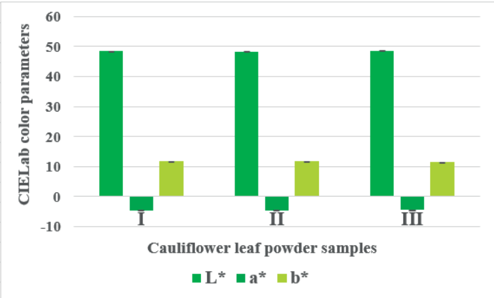

Figure 2. Colour parameters of the cauliflower leaf powder

Physico-chemical analysis

The physico-chemical indicators of the cauliflower leaf powder are presented in Table 1. The cauliflower leaf powders stand out for their protein content (28.72-29.95%), ash (10.39-11.23%), total sugars (17.85-21.05%) and total fiber (25.11-30.45%).

The protein content of cauliflower leaf powders obtained in this experimental study is higher compared to that reported by Chakraborty and Datta De (2016), 27.78 % and respectively by Perna et al. (2019), 21.16 % d.m., in the case of this functional ingredient.

Table 1. The physico-chemical indicators of the cauliflower leaf powder

Physico-chemical indicators	Cauliflower leaf powder		
	Sample I	Sample II	Sample III
Moisture (%)	7.30±0.18	7.45±0.19	7.12±0.18
Ash (%)	10.39±0.16	10.65±0.16	11.23±0.17
Protein (%)	28.72±0.43	29.08±0.44	29.95±0.45
Fat (%)	4.25±0.06	4.53±0.06	4.77±0.06
Carbohydrates (%)	49.34±0.32	48.29±0.31	46.93±0.30
Soluble sugars (%)	17.85±0.12	18.65±0.12	21.05±0.14
Total fiber (%)	30.45±0.56	29.03±0.54	25.11±0.46
Energy value (kcal/100g)	290	292	300
Energy value (kJ/100g)	1210	1222	1257

According to the provisions of Regulation (EC) No 1924/2006 of the European Parliament and of the Council, the cauliflower leaf powders are sources of proteins since at least 12% of their energy value is represented by proteins. Therefore, this functional ingredient can be used for fortification of food products in order to increase its protein content.

The ash content of cauliflower leaf powders obtained in this experimental study is higher compared to that reported by Drabiańska et al. (2021), in the case of fine powder obtained by freeze-dried and ground cauliflower leaves: 10.13 %. The high ash content of the functional ingredient obtained by utilizing cauliflower leaves actually highlights its high mineral element content.

It is worth noting the content in soluble sugars of the cauliflower leaf powder: 17.85-21.05%, respectively, 19.26% s.u.- 22.67% s.u. Collado-González et al. (2022) mention the fact that in the case of cauliflower leaves, the soluble sugars are represented by fructose, glucose, sucrose and inositol, their content being in the range: 15.96% s.u.- 44.58% s.u. The content of soluble sugars of the cauliflower leaf powders obtained in this study is located in the range mentioned above, reported by Collado-González et al. (2022).

The cauliflower leaf powder is an important source of fiber. The fiber content of the cauliflower leaf powders obtained in our research is lower than that reported by Ribeiro et al. (2015), in the case of cauliflower leaves flour 33.22%. It should be noted that the cauliflower leaf powders have a fiber content of 1.35-1.64 times higher than the fiber content of dried cauliflower, reported by Baloch et al. (2015): 18.59%.

Dietary fiber has a major impact on human health. Thus, they can have direct and indirect effects on the immune system when introduced into the diet. Before being fermented by microbes in the colon, dietary fiber can have a substantial impact on the gut by modulating intestinal barrier function and the immune response (Cai et al., 2020).

At the same time, Bhoite et al. (2021) mention that foods rich in protein and dietary fiber could improve the lipid profile in overweight or obese diabetic patients with dyslipidemia, reducing their risk of cardiovascular disease. These authors showed in a study carried out for 24 weeks, on a group of overweight/obese adults, the fact that, along with an adequate diet, the twice-daily administration of a nutritional supplement with high fiber and protein content, caused a significant increase in HDL-cholesterol levels and a modest decrease in LDL-cholesterol levels.

Considering the fact that the cauliflower leaf powders have a high protein and fiber content, their use for the fortification of food products (bakery, pastry, etc.) or for making a food supplement is of real interest.

The cauliflower leaf powders are notable for their content in mineral elements (Na, K, Ca, Mg, Fe, Zn, Cu and Mn), which is presented in Figures 3 and 4. Among the mineral elements, in the case of the cauliflower leaf powders, potassium has the highest content, in the range of 3865.52-4178.21 mg/100 g (the minimum value was recorded in the case of sample I, and the maximum value in sample III). The potassium content of the cauliflower leaf powders is higher than that reported by Saleh (2022) in the case of cauliflower wastes powder: 3462.69 mg/100 g.

Several international studies have shown that potassium is an important mineral for the proper function of the human body. An adequate diet with an adequate level of potassium is important for the prevention of cancer and cardiovascular diseases (Kardalas et al., 2018; Tabasum et al., 2014). The World Health Organization recommends that adults consume at least 3,500 mg per day from food.

At the same time, the cauliflower leaf powders stand out for their high calcium content (772.23-812.21 mg/100 g), and can be considered a source of calcium in the food fortification process.

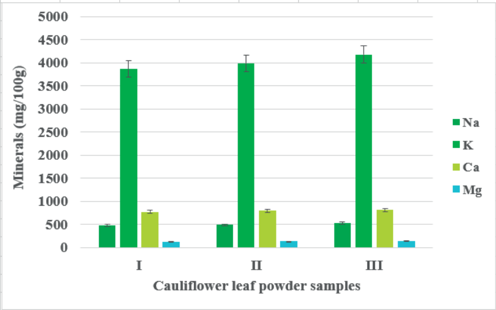

Figure 3. Mineral content (Na, K, Ca, and Mg) of the cauliflower leaf powder

The calcium content of the cauliflower leaf powders obtained in this study is higher than that reported by Saleh (2022) in the case of cauliflower waste powder: 750.40 mg/100 g. Also, it is worth noting that the cauliflower leaf powders have a calcium content about 2 times higher than that reported by Baloch et al. (2015), in the case of dried cauliflower: 395.03 mg/100 g. Calcium is one of the most abundant elements in the human body, which has a key role in skeletal mineralization, being necessary for normal bone growth, development and strength (Bootman et al., 2001). In addition, calcium plays a role in biological functions such as muscle contraction and nerve impulse transmission (Khundmiri et al., 2016).

The magnesium content of the cauliflower leaf powders varied between 120.23-145.85 mg/100 g, being higher than that reported by Saleh (2022) in the case of cauliflower wastes powder: 114.03 mg/100 g. At the same time, it is worth noting that the cauliflower leaf powders have higher magnesium content than that reported by Baloch et al. (2015), in the case of dried cauliflower: 117.87 mg/100 g.

Magnesium is one of the most important micronutrients, being essential for maintaining the normal function of cells and organs (Porri et al., 2021). At the same time, magnesium is important for maintaining muscle function and the nervous system, cardiac electrical properties and for supporting the immune system, as well as regulating glucose and insulin metabolism (Volpe, 2013).

The cauliflower leaf powders have an important sodium content, the highest value being registered in the case of sample III: 525.73 mg/100 g.

The cauliflower leaf powders can be considered sources of iron, as they recorded a high iron content, in the range of 40.75-51.15 mg/100 g (Figure 4).

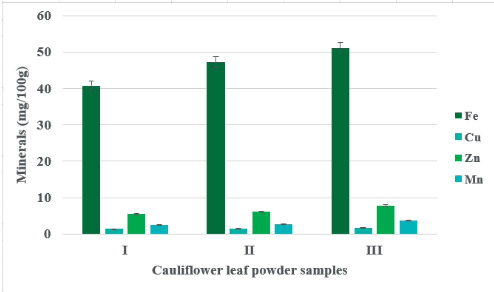

Figure 4. Mineral content (Fe, Zn, Cu and Mn) of the cauliflower leaf powder

According to the experimental data obtained, the iron content of the cauliflower leaf powders is higher than that reported by Saleh (2022) in the case of cauliflower waste powder: 37.85 mg/100 g. Iron has an essential role in cellular metabolism. The reduced form of iron is a cofactor in numerous redox reactions in the cell, intervening in many vital physiological functions. Most of the iron exists in the form bound to proteins, in erythrocytes in the form of hemoglobin and in storage proteins, such as ferritin, hemosiderin and myoglobin. Iron is also bound to non-heme proteins and enzymes involved in oxidation-reduction reactions and electron transfer (Salnikow, 2021). Iron is an important element in the treatment of nutritional deficiencies and iron deficiency anemia. Singh et al. (2019) studied the influence of some foods fortified with cauliflower leaf powder, on the nutritional status of rural school children from India. These fortified foods were administered to study participants (girls and boys aged 10-12 years) along with their daily diet for three months. At the end of the study, there was an increase in the height of the subjects (an average of 2.11 cm for boys and, respectively, an average of 1.26 cm for girls), an increase in weight (an average increase of 13.45% in the case of boys and 14.66% in the case of girls), increase in hemoglobin values (20.12%, in the case of boys of age 10 year+ and 12.83%, in the case of boys of age 11 year+; 8.33% in the case of girls of age 10 year+ and 13.75% of age

11 year+). The conclusion of the study was that the use of cauliflower leaf powder for the fortification of food products could improve the nutritional status of the population, controlling micronutrient deficiencies, especially iron deficiency anemia.

The zinc content of the cauliflower leaf powders recorded values in the range of 5.45-7.78 mg/100 g, lower than that reported by Saleh (2022), in the case of this functional ingredient: 23.45 mg/100 g. Zinc is an essential micronutrient for the health of the human body, intervening in the proper functioning of various cellular processes. In particular, zinc plays an important role in cellular antioxidant defense, the maintenance of DNA integrity, and the development and normal functioning of the immune system (Ho et al., 2022).

The manganese content of the cauliflower leaf powders was in the range of 2.52-3.63 mg/100 g, higher compared to that reported by Saleh (2022), in this functional ingredient: 0.14 mg/100 g.

The copper content of the cauliflower leaf powders recorded lower values, compared to the other elements identified and quantified in their case (1.39-1.67 mg/100 g).

Bioactive compounds content

Cauliflower leaf powders are notable for their content in bioactive compounds: total polyphenols (5.75-6.12 mg GAE/g d.u.), glucosinolates (240.23 - 259.65 mmol/g d.u.), vitamin C (76.50 - 89.44 mg/g s.u.), β-Carotene (39.45 - 47.21 mg/100 g), lutein (11.65 - 14.87 mg/100 g). The bioactive compound content of cauliflower leaf powders is shown in Table 2.

Table 2. Bioactive compounds content of the cauliflower leaf powder

Bioactive compounds	Cauliflower leaf powder		
	Sample I	Sample II	Sample III
Total polyphenols (mg GAE/g s.u.)	5.75±0.14	5.92±0.15	6.12±0.15
Glucosinolates (mmol/g s.u.)	240.23±5.77	252.12±6.05	259.65±6.23
Vitamin C (mg/100g)	76.50±2.29	80.23±2.41	89.44±2.68
β-Carotene (mg/100g)	39.45±0.91	42.49±0.98	47.21±1.09
Lutein (mg/100g)	11.65±0.27	13.24±0.30	14.87±0.34

The total polyphenol content of cauliflower leaf powders obtained in this experimental study is higher than that reported by Drabiańska et al. (2021), in the case of fine powder obtained from lyophilized and ground cauliflower leaves: 4.40 mg GAE/g.s.u.

Polyphenols are a very important class of phytochemical compounds and have several beneficial health effects due to their antioxidant and anti-inflammatory properties.

Epidemiological studies have shown a lower risk of chronic diseases (cardiovascular diseases, cancer, hypertension, diabetes) and neurodegenerative diseases, in the case of people who approach a diet rich in polyphenols (Voss et al., 2022).

The cauliflower leaf powders are important sources of glucosinolates, the content of these bioactive compounds being in the range of 240.23-259.65 mmol/g s.u. The content of these bioactive compounds is higher than that reported by Drabiańska et al. (2021), in the case of cauliflower leaf powder 225.2 mmol/g s.u. It is worth noting that the cauliflower leaf powders have a glycosinolate content of 2.55-2.76 times higher than the powder obtained by freeze-dried and ground of florets, which according to the research undertaken by Drabiańska et al. (2021), has a glycosinolate content of 94.02 mmol/g s.u. Glucosinolates are highly valuable bioactive compounds for health, providing protection against serious diseases such as colorectal cancer, prostate cancer, breast cancer, and myocardial infarction (Akram et al., 2021).

Also, the cauliflower leaf powders have a high content in vitamin C (76.50-89.44 mg/100 g), comparable to that of fresh cauliflower (florets). Vitamin C is an important antioxidant. Thus, vitamin C is involved in the primary prevention of coronary heart disease, stroke and cancer (Granger and Eck, 2018).

The cauliflower leaf powders are notable for their carotenoid content. Thus, the β-Carotene (39.45-47.21 mg/100 g) and lutein (11.65-14.87 mg/100 g) content of this functional ingredient is higher, compared to that reported for these bioactive compounds by Nartea et al. (2023), in the case of cauliflower leaf flour (β-Carotene: 35.73 mg/100 g; Lutein: 10.35 mg/100 g). Carotenoids are phytochemical compounds with important photoprotective and antioxidant properties. Dietary supplementation with carotenoids provides protection against diabetes, inflammatory diseases, and cancer (Swapni et al., 2021)

Antioxidant capacity

Due to the high antioxidant content, the cauliflower leaf powders show important antioxidant activity. Their antioxidant activity varied between 13.36 - 14.2 µmol TE/g (the minimum value was recorded in the case of sample I, and the maximum value in sample III) (Figure 5).

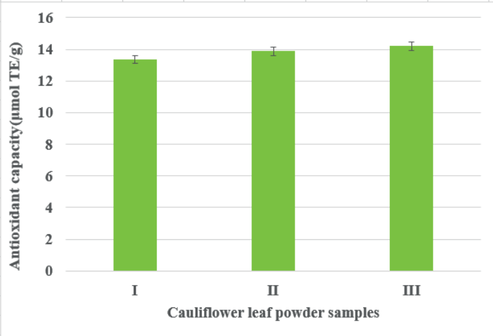

Figure 5. Antioxidant capacity of the of the cauliflower leaf powder

For the cauliflower leaf powders between the total polyphenol content and antioxidant capacity it is a linear correlation ($y = 2.2507x + 0.4665$; $R^2 = 0.9667$).

Microbiological analysis

The microbiological indicators of the cauliflower leaf powders are presented in Table 3.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 should be noted that of the cauliflower leaf powders have low values for water activity (0.180-0.203), which ensures their stability from a qualitative point of view.

Table 3. Microbiological analysis of the cauliflower leaf powder

Microbiological indicators	Cauliflower leaf powder		
	Sample I	Sample II	Sample III
Yeasts and molds (CFU/g)	< 10	< 10	< 10
Enterobacteriaceae (CFU/g)	< 10	< 10	< 10
Water activity	0.194	0.203	0.180

The results of the microbiological analysis highlight the fact that the cauliflower leaf powders can be used under food safety conditions, in the fortification of food products.

CONCLUSIONS

The research undertaken has highlighted the high nutritional and bioactive potential of cauliflower leaves and the fact that they should not be regarded as waste, but should be considered as sources of nutrients and bioactive compounds. The functional ingredients (powders) obtained by utilizing cauliflower leaves stand out for their protein content (28.72-29.95%), ash (10.39-11.23%), total sugars (17.85-21.05%) and total fiber (25.11-30.45%). It is also worth noting the high content of mineral elements (potassium 3865.52-4178.21 mg/100 g; calcium: 772.23-812.21 mg/100g; magnesium: 120.23- 145.85 mg/100g; sodium: 475.58-525.73 mg/100 g; iron: 40.75-51.15 mg/100 g; zinc: 5.45-7.78 mg/100 g; manganese: 2.52-3.63 mg/100 g; copper: 1.39-1.67 mg/100 g).

At the same time, these functional ingredients are sources of bioactive compounds: total polyphenols (5.75-6.12 mg GAE/g s.u.), glucosinolates (240.23 - 259.65 mmol/g s.u.), vitamin C (76.50 - 89.44 mg/100 g), β-Carotene (39.45 - 47.21 mg/100 g), lutein (11.65 - 14.87 mg/100 g).

The microbiological analyzes carried out showed that the cauliflower leaf powders are safe for human consumption.

Due to the high content in nutrients, bioactive compounds and antioxidant potential, the cauliflower leaf powders can be used in food safe conditions, in the process of fortification of food products (for example, bakery products, pastries), in order to increase the nutritional value and of their antioxidant capacity.

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