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RESEARCH ON THE UTILIZATION OF NUTRIENTS AND BIOACTIVE COMPOUNDS FROM CAULIFLOWER STALKS, THROUGH THE DEVELOPMENT OF A FUNCTIONAL INGREDIENT WITH HIGH NUTRITIONAL VALUE AND ANTIOXIDANT CAPACITY

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Abstract

Agricultural production and the food industry generate a large amount of waste, with a major impact on the environment. The Action Plan for the European Strategy for the Circular Economy includes a zero-waste strategy targeting agri-food waste to reduce environmental pollution. The aim of this study was to valorize cauliflower stalks in order to obtain a functional ingredient rich in nutrients and bioactive compounds, which confer antioxidant capacity. This functional ingredient appears as a powder with characteristic taste and smell, in a whitish-yellow or whitish-gray color, with a high content of proteins (23.12-24.09%), available carbohydrates (29.21-31.81%), total fiber (23.27-26.85%), mineral elements (K: 1785.35-2175.23 mg/100 g; Ca: 505.35-598.86 mg/100 g; Mg: 97.56-128.56 mg/100 g; Fe: 28.43-43.57 mg/100 g; Zn: 4.27-5.62 mg/100 g), bioactive compounds (total polyphenols: 4.52-5.47 mg GAE/g d.w.; glucosinolates: 7.28-8.20 µmol/g d.w.; vitamin C: 45.03-48.12 mg/100 g). The functional ingredient obtained from cauliflower stalks stands out for its ability to neutralize free radicals (10.72-12.94 µmol Trolox Equivalents/g).

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

INTRODUCTION

According to the "Food 2030 Pathways for Action" (Directorate-General for Research and Innovation, 2020), primary production (25%) and processing (24%) account for approximately 50% of total food losses, with fruits and vegetables representing the largest share of these losses. In the early stages of processing, these losses are mainly caused by disposal due to high commercial standards, as well as edible parts that are removed during peeling or cutting in fresh processing lines (outer leaves, stalks, damaged parts).

It is necessary for production systems to focus on minimizing waste and reintroducing it into the production chain. In this regard, concepts such as "circular economy," "industrial ecology," and "zero-waste economy," among others, have emerged to guide eco-innovation towards using waste as raw material for the development of new products and applications (Ramírez-Pulido et al., 2021). Reducing food waste is also an important contribution to the Circular Economy Action Plan adopted by the European Commission within the European Green Deal, which promotes sustainable initiatives throughout the entire product lifecycle. A circular approach brings benefits to sustainable food production (European Commission, 2019).

The vegetable processing industry produces over one million tons of plant by-products, considered waste, every year, which represents a potential source of bioactive ingredients (Galali et al., 2020; Rafiuddin et al., 2019; 2021). International studies have shown that there is a huge potential in utilizing plant-based by-products for the development of food products (Amoah et al., 2023; San José et al., 2018; Tamasi et al., 2019). In this regard, cauliflower by-products (which account for about 60% of the cauliflower crop) are among the most important, distinguished by their content of nutrients and bioactive compounds (polyphenols, glucosinolates, carotenoids, vitamin C, chlorophyll a, chlorophyll b, etc.). Thus, Drabińska et al. (2021) mentioned that the powder obtained from cauliflower stems stands out due to its ash content (11.78%), protein content (19.12%), and carbohydrates (64.36%). Additionally, based on their research, these authors highlighted that the powder from cauliflower stems is remarkable for its total amino acid content: 2422.64 µmol/g dry matter. The amino acids that are most abundant in this powder are as follows: Glutamine (1009.42 µmol/g dry matter), Valine (100.01 µmol/g dry matter), Alanine (341.32 µmol/g dry matter), Serine (268.31 µmol/g dry matter), Asparagine (205.97 µmol/g dry matter), Glutamic acid (193.56 µmol/g dry matter).

Furthermore, Drabińska et al. (2021) showed that the powder from cauliflower stems is rich in glucosinolates (125.05 mmol/g dry matter), total polyphenols (2.65 mg GAE/g dry matter), and chlorophyll b (0.66 µg/g dry matter). Tukassar et al. (2023) mentioned that cauliflower by-products powder is notable for its ash content (5.81%), protein content (22.80%), carbohydrates (47.62%), minerals (Mg = 363 mg/kg; Fe = 200.30 mg/kg; Zn = 14.60 mg/kg), total phenolic compounds (537.40 mg GAE/100 g), and demonstrates antioxidant capacity (DPPH inhibition activity = 96.75%). Due to the high nutritional value, bioactive compound content, and antioxidant properties of cauliflower stems, their valorization is of significant interest.

This paper presents the nutrient content, bioactive compounds, and antioxidant capacity of a functional ingredient (powder) obtained through the valorization of cauliflower stems.

MATERIALS AND METHODS

Samples

Cauliflower stalks were procured from Romanian farmers (three farmers from Ialomița County). The experiments were carried out at IBA-Bucharest, within the Pilot Vegetable-Fruit Processing Experimental Station.

The technological process for obtaining the powder from cauliflower stalks includes the following technological operations: sorting, washing, cleaning, division, boiling in water at 98-100°C for 4-5 minutes, dehydration, grinding, and packaging.

The dehydration of the plant material was carried out with hot air at a temperature of 50°C, in a convective electric dryer (Memmert), on stainless steel trays, with a hot air speed of 2.3 m/s, for 15.5-16 hours, until a maximum moisture content of 8.5%.

The grinding of the dehydrated plant material was carried out using a Knife Mill Grindomix GM 200, at a temperature of 20-22°C, to prevent the degradation of bioactive compounds and the properties of the functional ingredient (powder). The functional ingredient (powder) was packaged in glass containers, protected with aluminum foil, and sealed hermetically using twist-off lids.

The Figure 1 show cauliflower stalks powder three samples, from three different sources (farmers).

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

Statistical Analysis

The cauliflower stalks powder samples were analyzed in triplicate, and the results obtained are presented as the arithmetic mean and standard deviation.

Sensory analysis

The sensory analysis of the cauliflower stalks powder samples was carried out by evaluating the sensory characteristics (appearance, color, taste, and odor).

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

Physico-chemical analysis

The nutritional composition of the cauliflower stalks powder samples was determined using AOAC methods: 979.09 (protein content), 963.15 (fat content), 923.03 (ash content), and 985.29 (total dietary fiber). The moisture content of the cauliflower stalks powder samples was determined using the Halogen

Moisture Analyzer HE53 (Mettler Toledo). Total carbohydrates were calculated with the formula: 100 (%) - moisture (%) - protein (%) - fat (%) - total dietary fiber (%). The energy value was calculated using conversion factors of 9 kcal/g for fat, 4 kcal/g for carbohydrates and protein, and 2 kcal/g for fiber, in accordance with 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

The determination of the total polyphenol content was carried out using the Folin-Ciocalteau spectrophotometric method, according to Horszwald and Andlauer (2011), with some modifications (extraction medium, method and extraction time, volume of extract used in the analysis), using a UV-VIS Jasco V 550 spectrophotometer at a wavelength of λ = 755 nm. For quantification, a calibration curve of gallic acid in the concentration range of 0-0.20 mg/mL was used, and the results were expressed as mg of Gallic Acid Equivalents (GAE) per g of cauliflower stalks powder.

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 vitamin E (α-tocopherol) content was determined by chromatographic method (HPLC-DAD) (Popović et al., 2015). The content of glucosinolates was determined using a spectrophotometric method (Mawlong et al., 2017). The total carotenoid content was determined using a spectrophotometric method (Chinnadurai et al., 2013).

Antioxidant capacity

Antioxidant capacity was performed by the DPPH (1,1-diphenyl-2-picryl hydrazyl) method, according to Horszwald and Andlauer (2011), with some modifications (extraction medium, method and extraction time, volume of extract used in the analysis), using a UV-VIS Jasco V 550 spectrophotometer, at a wavelength of λ = 517. For quantification, a calibration curve of Trolox (6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic Acid) in the concentration range of 0-0,4375 mmol/L was used, and the results were expressed as µmol Trolox Equivalents per g of cauliflower stalks powder.

Microbiological analysis

The microbiological analysis of the cauliflower stalks powder was carried out 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

The sensory analysis highlighted that the functional ingredient obtained from cauliflower stalks appears as a white-yellowish powder with a characteristic taste and smell typical for the Cruciferous family.

Following the instrumental color analysis (Figure 2), it was found that the powder obtained from the cauliflower stalks recorded high values of luminance L, ranging from 83.78 to 85.89. The b parameter varied between 21.01 and 22.87. The lowest values were recorded for the a* parameter (2.21-3.46). The luminance L* values recorded for the powder obtained from cauliflower stalks are significantly higher compared to those reported by Drabiańska et al. (2021) for the powder obtained from cauliflower leaves by lyophilization and grinding: L* = 43.51.

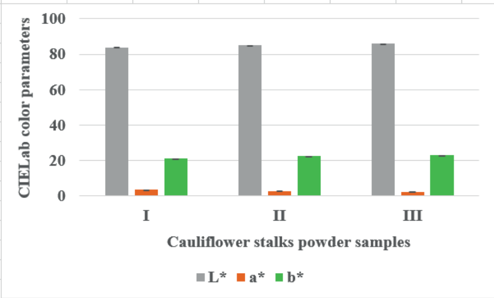

Figure 2. Colour parameters of the cauliflower stalks powder

At the same time, the values of the b parameter are 3.71-4.04 times higher compared to those reported by Drabiańska et al. (2021) for the powder obtained from cauliflower leaves by lyophilization and grinding: b = 5.66.

Physico-chemical analysis

The physico-chemical composition of the cauliflower stalks powder is presented in Table 1. The cauliflower stalks powders stand out for their carbohydrate content (55.08-57.50%), available carbohydrates (29.21-31.81%), soluble sugars (14.32-16.73%), protein (22.33-24.09%), ash (9.12-9.73%), and total fiber (23.27-26.85%).

Table 1. The physico-chemical composition of the cauliflower stalks powder

Physico-chemical composition	Cauliflower stalks powder		
	Sample I	Sample II	Sample III
Moisture (%)	6.90±0.17	6.72±0.17	6.61±0.17
Ash (%)	9.12±0.14	9.45±0.14	9.73±0.15
Protein (%)	22.33±0.33	23.12±0.35	24.09±0.36
Fat (%)	4.15±0.05	4.28±0.06	4.49±0.07
Carbohydrates (%)	57.50±0.37	56.43±0.37	55.08±0.36
Available carbohydrates (%)	30.65±0.20	29.21±0.19	31.81±0.20
Soluble sugars (%)	14.32±0.09	15.65±0.10	16.73±0.11
Total fiber (%)	26.85±0.50	25.42±0.47	23.27±0.43
Energy value (kcal/100g)	303	306	311
Energy value (kJ/100g)	1269	1282	1303

The ash content of the cauliflower stalks powder obtained in this experimental study is lower compared to that reported by Drabińska et al. (2021), 11.78%, in the case of this powder. At the same time, the ash content of the cauliflower stalks powder obtained in this study is 2-2.13 times higher compared to that reported by Sharma and Prasad (2018) for this functional ingredient. The protein content of the functional ingredient (powder) obtained from cauliflower stalks is higher compared to that reported by Drabińska et al. (2021), 19.12%, and by Sharma and Prasad (2018), 17.02%, in the case of this powder. The cauliflower stalks powders are sources of protein, since, according to Regulation (EC) No 1924/2006 of the European Parliament and of the Council, at least 12% (in this case 29.48%-30.98%) of their energy value comes from proteins.

The lipid content of cauliflower stalks powder is comparable to that reported by Drabińska et al. (2021): 4.74%. The carbohydrate content of the cauliflower stalks powder is about 1.17 times higher compared to that reported by Catană et al. (2023) for the cauliflower leaves powder (46.93%-49.34%), and 1.07-1.11 times higher compared to that reported by Sharma and Prasad (2018) for cauliflower stalks powder (51.56%).

The cauliflower stalks powders are significant sources of fiber (23.27%-26.85%). The fiber content of the cauliflower stalks powders obtained in our research is 1.45-1.68 times higher than that reported by Sharma and Prasad (2018) for this functional ingredient. At the same time, the fiber content of the cauliflower stalks powders is lower compared to that reported by Catană et al. (2023) for the cauliflower leaves powder (25.11%-30.45%). International studies demonstrate the importance of fiber in a healthy diet and its beneficial effects on the human body. Thus, fibers have water-holding capacity, reducing food intake (Dhingra et al., 2012; Liu et al., 2020), gelling capacity, increasing satiety (Wanders et al., 2013), glucose absorption capacity, lowering blood glucose (Liu et al., 2020), cholesterol-binding capacity, lowering serum cholesterol (Massa et al., 2022), antitumor capacity (Tang et al., 2024), and immunomodulatory activity (Dong et al., 2023; Tang et al., 2024). Given the beneficial effects of fibers on the human body, fortifying bakery and pastry products with cauliflower stalks powders is of real interest.

The mineral content of the cauliflower stalks powders is presented in Figures 3, 4, and 5. Potassium has the highest content among the analyzed mineral elements, ranging from 1785.35 to 2175.23 mg/100 g (the minimum value was recorded in sample I, and the maximum value in sample III)."

The potassium content of the cauliflower stalk powders is 1.92 to 2.16 times lower compared to that reported by Catană et al. (2023) for cauliflower leaf powder.

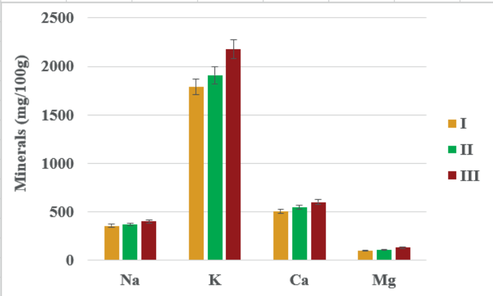

Figure 3. Mineral content (Na, K, Ca, and Mg) of the cauliflower stalks powders

Potassium is the main intracellular cation in the body and is particularly involved in membrane potential and electrical excitation of both nerve and muscle cells, as well as in acid-base regulation. Increased potassium intake lowers blood pressure, and this effect is especially important in hypertensive individuals (Frassetto et al., 2023).

Given these positive effects of potassium, fortifying food products (especially bakery and pastry products) with functional ingredients rich in potassium is of real interest.

Additionally, the cauliflower stalk powders have a high calcium content: 505.35-598.86 mg/100 g. By fortifying food products with this functional ingredient, their calcium content is increased.

Calcium is an important mineral that plays an essential role in human health, especially in bone health (Xu et al., 2020).

Calcium deficiency can lead to conditions such as osteoporosis, rickets, epilepsy, and anemia (Shojaeian et al., 2019).

The magnesium content of the cauliflower stalk powders ranged from 97.56 to 128.56 mg/100 g, being 2.69 to 3.54 times higher compared to the magnesium content in cauliflower by-products powder: 36.3 mg/100 g (Tukassar et al., 2023).

The iron content of the cauliflower stalk powders ranged from 28.43 to 43.57 mg/100 g, being 1.62 to 2.48 times higher than the iron content reported by Sharma and Prasad (2018) for this functional ingredient.

The iron content of Sample III from this experimental study is comparable to that reported by Catană et al. (2023) for cauliflower leaf powders, Sample I: 40.75 mg/100 g.

Iron plays a major role in the proper functioning of the human body. It is vital in oxygen transport, being the main component of hemoglobin and myoglobin, and also plays a role in oxidative phosphorylation.

Iron deficiency leads to iron-deficiency anemia and may contribute to cardiovascular disease, cancer, and developmental disorders of the brain and central nervous system (Samarakoon et al., 2023).

Therefore, fortifying food products with iron from natural sources is important.

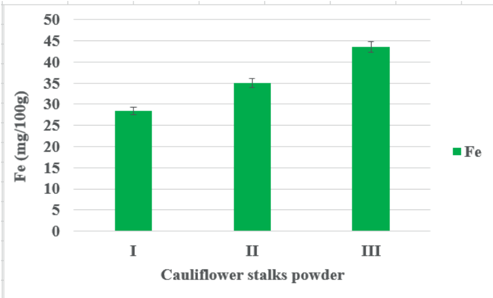

Figure 4. Iron content of the cauliflower stalks powders

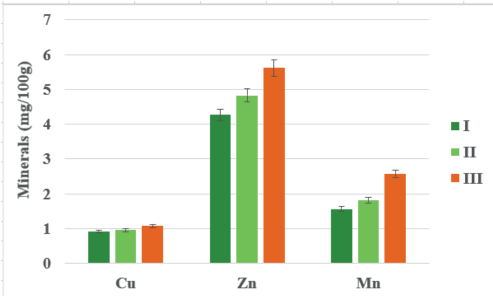

Figure 5. Mineral content (Zn, Cu and Mn) of the cauliflower stalks powder

The zinc content of the cauliflower stalk powder ranged between 4.27 and 5.62 mg/100 g. The manganese and copper content of the functional ingredient obtained from the valorization of cauliflower stalks is lower compared to the zinc content (Mn: 1.56-2.58 mg/100 g; Cu: 0.92-1.07 mg/100 g). The manganese content of the cauliflower stalk powders is significantly higher compared to that reported by Saleh (2022) for cauliflower waste powder (0.14 mg/100 g).

Bioactive compounds content

Cauliflower stalk powders exhibit a notable biochemical composition, characterized by their content of bioactive compounds (total polyphenols: 4.52-5.47 mg GAE/g d.w.; glucosinolates: 7.28-8.20 μmol/g d.w.; vitamin C: 45.03-48.12 mg/100 g; α-tocopherol: 1.05-1.44 mg/100 g; total carotenoids: 0.287-0.305 mg/100 g).

The results are in agreement with those obtained by Tlais et al. (2020), who state that, in addition to glucosinolates, cauliflower by-products are also notable for their content of vitamin C, carotenoids, and phenolic compounds.

Table 2 presents the bioactive compound content of the cauliflower stalk powders.

Table 2. Bioactive compounds content of the cauliflower stalks powders

Bioactive compounds	Cauliflower stalks powder		
	Sample I	Sample II	Sample III
Total polyphenols (mg GAE/g d.w.)	4.52±0.11	5.36±0.13	5.47±0.14
Glucosinolates (μmol/g d.w.)	7.28±0.18	7.87±0.20	8.20±0.21
Vitamin C (mg/100g)	48.12±1.44	46.24±1.39	45.03±1.35
α-Tocopherol (mg/100g)	1.05±0.03	1.27±0.03	1.44±0.04
Total carotenoids (mg/100g)	0.287±0.002	0.295±0.003	0.305±0.003

The total polyphenol content of the cauliflower stalk powders obtained in this study is 1.70 to 2.06 times higher than that reported by Drabiańska et al. (2021) for fine powder obtained from lyophilized and ground cauliflower stalks (2.65 mg GAE/g d.w.). Moreover, the total polyphenol content in this study is comparable to the value reported by Tukassar et al. (2023) for cauliflower by-products powder (5.37 mg/g).

Polyphenols represent an important class of biochemical compounds with beneficial effects on human health. Epidemiological studies conducted worldwide have shown that moderate and long-term consumption of polyphenol-rich foods may help prevent the development of cancer and chronic diseases such as cardiovascular and neurodegenerative diseases, type 2 diabetes, and obesity (Bié et al., 2023).

Additionally, cauliflower stalk powders are notable for their glucosinolate content, ranging from 7.28 to 8.20 μmol/g d.w. This is lower than the levels reported by Catană et al. (2023) for cauliflower leaf powders (240.23-259.65 μmol/g d.w.).

Recent research supports the protective role of glucosinolates in chronic diseases through mechanisms involving modulation of oxidative stress, inflammation, and detoxification pathways. Upon consumption, glucosinolates undergo enzymatic hydrolysis by myrosinase, resulting in the formation of bioactive compounds such as isothiocyanates and specific degradation products of indole glucosinolates, such as indole-3-carbinol and 3,3′-diindolylmethane, which contribute to various health benefits including anticancer, anti-inflammatory, and cardioprotective effects (Baldelli et al., 2025).

The vitamin C content of the cauliflower stalk powders ranged from 45.03 to 48.12 mg/100 g, being 1.70 to 1.86 times lower than the content reported by Catană et al. (2023) for cauliflower leaf powders (76.50-89.44 mg/100 g). However, the vitamin C content found in this study is comparable to the value reported by Kaviyarasi and Subapriya (2024) for dried cauliflower leaves (52 mg/100 g).

Vitamin C is an important cofactor in collagen and hormone synthesis and is involved in immune function, iron absorption, and antioxidant-related processes. Furthermore, it plays a significant role in improving quality of life, preventing chronic diseases and cardiovascular conditions, and is used in treatments for infections, neurodegenerative diseases, and cancer (Alberts et al., 2025).

The vitamin E (α-tocopherol) content of the cauliflower stalk powders ranged from 1.05 to 1.44 mg/100g, which is comparable to the value reported by Catană et al. (2021) for elderberry pomace powder obtained through hot air drying at 50°C (Sample II = 1.50 mg/100 g).

α-Tocopherol is an important peroxyl radical scavenger, playing a key role in maintaining metabolic health in tissues (Traber, 2023).

Cauliflower stalk powders also have a low total carotenoid content, ranging from 0.287 to 0.305 mg/100g.

Antioxidant capacity

Due to their complex biochemical composition, the cauliflower stalk powders exhibit antioxidant capacity, ranging from 10.72 to 12.94 μmol Trolox Equivalents/g (Figure 6).

The antioxidant capacity of the cauliflower stalk powders is 1.10 to 1.25 times lower compared to that reported by Catană et al. (2023) for cauliflower leaf powders, which ranged from 13.36 to 14.2 μmol TE/g.

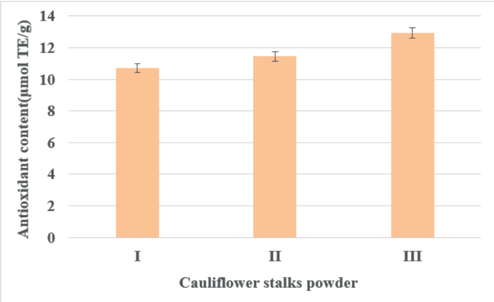

Figure 6. Antioxidant capacity of the cauliflower stalks powders

Microbiological analysis

The cauliflower stalks were processed under food-safe conditions, and the microbiological analysis of the cauliflower stalk powders showed that they comply with the current legal regulations (Table 3).

Table 3. Microbiological analysis of the cauliflower stalks powders

Microbiological indicators	Cauliflower stalks powder		
	Sample I	Sample II	Sample III
Yeast and molds (CFU/g)	< 10	< 10	< 10
Enterobacteriaceae (CFU/g)	< 10	< 10	< 10
Water activity	0.266	0.257	0.246

The cauliflower stalk powders recorded low water activity values (0.246-0.266), which contributes to their quality stability in terms of sensory, physicochemical, microbiological properties, and bioactive compound content.

CONCLUSIONS

The research conducted in this experimental study revealed that cauliflower stalks possess a complex biochemical composition, and their valorization in the form of powders is of significant interest. Thus, based on a proprietary technology and under food-safe conditions, the cauliflower stalks were processed into powders with high nutritional value and notable antioxidant capacity.

The cauliflower stalk powders stand out for their content of protein (22.33-24.09%), ash (9.12-9.73%), available carbohydrates (29.21-31.81%), soluble sugars (14.32-16.73%), and total fiber (23.27-26.85%).

Additionally, the cauliflower stalk powders are rich in minerals, particularly potassium, calcium, magnesium, iron, and zinc (K: 1785.35-2175.23 mg/100 g; Ca: 505.35-598.86 mg/100 g; Mg: 97.56-128.56 mg/100 g; Fe: 28.43-43.57 mg/100 g; Zn: 4.27-5.62 mg/100 g).

These powders are also valuable due to their bioactive compound content (total polyphenols: 4.52-5.47 mg GAE/g d.w.; glucosinolates: 7.28-8.20 μmol/g d.w.; vitamin C: 45.03-48.12 mg/100 g; α-tocopherol: 1.05-1.44 mg/100 g; total carotenoids: 0.287-0.305 mg/100 g). Moreover, the functional ingredient obtained from cauliflower stalks exhibits the ability to neutralize free radicals, with an antioxidant capacity ranging from 10.72 to 12.94 μmol Trolox Equivalents/g.

Due to their high nutritional value, rich bioactive compound profile, and antioxidant capacity, cauliflower stalk powders represent valuable functional ingredients that can be successfully used in the fortification of food products.

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