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Nutritional Composition, Polyphenol Content, and Antioxidant Activity of Swiss Chard (*Beta vulgaris* L. subsp. cicla)

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Swiss chard (*Beta vulgaris* L. subsp. *cicla*) is a nutritionally rich leafy vegetable valued for its high bioactive compounds and essential mineral content. This study aimed to evaluate the total polyphenol content (TPC), antioxidant activity (AA), macro- and microelement concentrations, and the presence of selected risk elements (lead and cadmium) in different plant parts (leaves and stems) of two Swiss chard samples. The results revealed that leaves consistently exhibited higher levels of TPC and AA than stems, with values reaching up to 9,634 mg GAE.kg^{-1} DM and 15.9 mmol TE.kg^{-1} DM, respectively. Mineral analysis confirmed Swiss chard as a good calcium, magnesium, potassium, and iron source, with significant variation between leaves and stems. While leaves were richer in calcium, magnesium, iron, manganese, and zinc, stems contained higher levels of sodium and potassium. Trace element analysis indicated the presence of lead and cadmium in all samples, with lead exceeding the permissible limit in the leaves of one sample. The findings emphasize both the nutritional potential of Swiss chard and the need for environmental monitoring to ensure food safety. The observed variability in chemical composition highlights the influence of plant part, genotype, and environmental conditions. Overall, Swiss chard represents a promising functional food, particularly when cultivated under controlled agroecological practices that minimize contaminant exposure.

Keywords: Swiss chard, minerals, cadmium, lead, polyphenols, antioxidant activity

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Introduction

Swiss chard (*Beta vulgaris* subsp. *cicla*), a member of the Amaranthaceae family, is a leafy vegetable cultivated globally not only for its culinary versatility but also for its nutritional profile, particularly its mineral content. Both the leaves and stems contribute beneficial compounds and should be considered important components of a balanced and health-promoting diet (Gamba et al., 2020). It is especially rich in essential minerals, such as calcium, magnesium, potassium, and iron, and polyphenolic compounds, which together contribute to its role as a functional food. The combined presence of minerals and antioxidants in Swiss chard has been associated with protective effects against oxidative stress and chronic diseases, including cardiovascular disease and cancer. Multiple studies have demonstrated that leaves and stems of Swiss chard contain a diverse array of phenolic acids and flavonoids, including syringic acid, kaempferol, and vitexin derivatives, which exhibit significant radical scavenging activities (Pyo et al., 2004; Ninfali et al., 2007; Ivanović et al., 2018). Recent studies have also demonstrated the modulation of polyphenol content and antioxidant activity by external factors such as irrigation, fertilization, and post-harvest cooking techniques (Ivanović et al., 2021; Ozbek and Saral, 2023).

Beyond phenolic compounds, Swiss chard is also a noteworthy source of essential minerals such as magnesium, calcium, potassium, and iron, which not only contribute to its role in supporting metabolic and physiological functions but also synergize with antioxidants to enhance overall health outcomes (Ivanović et al., 2018; Gamba et al., 2020). The mineral composition can vary significantly depending on agronomic practices and environmental conditions, which may also influence the plant's phytochemical profile (Rioba et al., 2020).

Although mangold is cultivated to a lesser extent than other leafy vegetables such as lettuce and spinach, it holds comparable nutritional value and importance. Due to its rich composition of essential nutrients – including vitamins A, C, and E, folic acid, calcium, iron, and dietary fiber – Swiss chard is considered a valuable component of a health-promoting diet. The leaves are naturally low in calories and sodium and contain no cholesterol, making them an ideal food for individuals seeking to maintain cardiovascular and metabolic health. Regular consumption of leafy greens, including Swiss chard, has been associated with reduced body weight, lower blood cholesterol and blood pressure levels, and improved glycemic control, thereby decreasing the risk of cardiovascular diseases and type 2 diabetes (Szilágyi et al., 2019).

Despite its nutritional potential, Swiss chard remains underutilized in many regions. A better understanding of its composition can support dietary recommendations and guide breeding and cultivation practices aimed at improving food quality and public health. This manuscript investigates the total polyphenol content, antioxidant activity, and mineral composition of Swiss chard, and aims to establish Swiss chard as a valuable dietary component.

Material and Methodology

Plant Material

The researched samples of Swiss chard, cultivar Lucullus, were obtained from different retailers in Slovakia.

Extract Preparation

25 g of fresh homogenized samples were extracted in 50 ml of 80% methanol for 12 hours and filtered through filtrating paper.

Analysis of Macroelements

For analysis of macroelements, 1 g of homogenized dried sample was mineralized in a mixture of 10 ml of concentrated HNO_3 and 5 ml of concentrated HCLO using a closed microwave digestion system Mars Xpress 5 (CEM Corp., Matthews, NC, USA). After mineralization, cooled samples were filtered through quantitative filter paper Filtrak 390 (Munktell, GmbH, Bärenstein, Germany). For the K, Ca, Mg, and Na determination, 2 ml of filtered sample was diluted with redistilled water to the volume of 50 ml, and measured against a blank solution using atomic absorption spectrophotometer VARIAN AASpectra DUO 240FS (Varian, Ltd., Mulgrave, VIC, AUS). For the P determination, 1 ml of filtered sample was diluted with 8 ml of solution $\left(\left(C_6H_8O_6, H_2SO_4\ (NH_4)\ 2\ MoO_4, \text{ and } C_4H_4KO_7Sb{,}0 \times 5\ H_2O\right)\right)$ and deionized water to the volume of 50 ml, and measured against blank solution using a UV/ Visible Scanning Spectrophotometer Shimadzu UV-1800 (Shimadzu, Kyoto, Japan).

Analysis of Microelements

For analysis of microelements, 1 g of dried homogenised sample was mineralised in 5 mL of HNO_3 Suprapur® (Merck, Darmstadt, Germany) and 5 mL of deionised water (0.054 μS cm^{-1}), using a Mars Xpress 5 closed micro wave digestion system (CEM Corp., Matthews, NC, USA) at 160 °C for 15 minutes and maintaining it at constant temperature for 10 min. After digestion, sam ples were filtered through Filtrak 390 quantitative filter paper (Munktell, GmbH, Bärenstein, Germany) and filled to a volume of 50 mL with deionised water. The obtained filtrates were processed by Flame atomic absorption spectrophotometry (AAS) for Fe, Mn, Zn, Cu, Co, Ni and Cr using a Varian AASpectra DUO 240FS system and a Graphite Furnace AAS method for Cd and Pb using a Varian AASpectra DUO 240Z system (Mulgrave, VIC, AUS).

Total Polyphenol Content

Total polyphenol content was determined by the Folin-Ciocalteau colorimetric method (Lachman et al., 2003). Folin-Ciocalteu phenol reagent (Merck, Germany), 20% Na_2CO_3 (Sigma Aldrich, USA), and distilled water were used. 0.1 mL of extract was pipetted into a 50 mL volumetric flask. 0.85 mL of Folin-Ciocalteu reagent was added, and after 3 minutes, 5 mL of 20% Na_2CO_3 was added. The mixture was stirred, and the flask was filled with distilled water to the mark. Flasks were left for 2 hours at laboratory temperature and then measured against a blank solution at 765 nm, using a Shimadzu UV/VIS scanning spectrophotometer. Total polyphenol content was expressed as mg of gallic acid equivalent per 1 kg, based on the calibration curve.

Antioxidant Activity

Antioxidant activity was measured by DPPH radical scavenging assay (Brand Williams et al., 1995). DPPH•+ radical (2,2-diphenyl-1-picrylhydrazyl) (Sigma Aldrich, USA) and methanol (Sigma Aldrich, USA) were used to produce a working DPPH solution. 1 mL of extract was pipetted into 3.9 mL of working DPPH solution, stirred, and left in the dark. After 10 minutes, the solution was measured against a blank solution at nm, using a Shimadzu UV/VIS scanning spectrophotometer. Antioxidant activity was expressed at 130 as mmol of Trolox equivalent in 1 kg, based on the calibration curve.

Statistical Analysis

Statistical analysis was performed using XLSTAT software (Lumivero, 2025). To compare the measured parameters between the two Swiss chard parts, appropriate parametric or non-parametric tests were applied based on the distribution of the data. Normality of the data was assessed using the Shapiro-Wilk test. For variables that followed a normal distribution, comparisons between samples were conducted using the independent samples *t*-test. In cases where the assumption of normality was not met, the non-parametric Mann-Whitney U test was applied. Statistical significance was set at $p < 0.05$. All results are presented as mean ± standard deviation (SD), and all measurements were performed in quadruplicate.

Results and Discussion

Content of Biogenic and Risk Elements in the Swiss Chard

The macromineral profile of Swiss chard revealed considerable variation between stems and leaves, as well as between the two samples (Table 1). Potassium (K) was the most abundant macronutrient in all plant parts, with values ranging from 20,277 to 25,724 $mg.kg^{-1}$ DM. Calcium (Ca) and magnesium (Mg) were significantly more concentrated in the leaves of both samples, with the highest Ca (5,913 $mg.kg^{-1}$ DM) and Mg (6,678 $mg.kg^{-1}$ DM) levels detected in the leaves of Sample 2. Phosphorus (P) content was relatively uniform across samples and tissues, ranging from 2,864 to 3,571 $mg.kg^{-1}$ DM, with slightly higher concentrations in leaves. Sodium (Na), though not an essential macronutrient for most plants, showed pronounced variability. In Sample 2, stems exhibited an exceptionally high Na concentration (36,356 $mg.kg^{-1}$ DM), suggesting possible exposure to saline conditions or soil contamination. Overall, the leaf tissues demonstrated a richer profile of Ca and Mg, supporting their higher metabolic and structural demands, while stems, particularly from Sample 2, accumulated disproportionately high levels of Na, potentially posing concerns for salt-sensitive consumers. According

Table 1 Content of macroelements in the analyzed samples ($mg.kg^{-1}$ DM)

Sample	Part	K	Ca	Mg	P	Na
1	stem	25,724 ±1,286^a	2,377 ±113^a	3,138 ±128^a	3,442 ±189^a	18,453 ±849^b
	leaves	24,472 ±1,239^a	5,507 ±289^b	4,651 ±211^b	3,571 ±199^a	14,540 ±695^a
2	stem	25,129 ±1,198^b	1,994 ±113^a	2,348 ±158^a	2,864 ±168^a	36,356 ±1694^b
	leaves	20,277 ±1,125^a	5,913 ±249^b	6,678 ±308^b	3,528 ±166^b	29,664 ±1128^a

Notes: Different letters indicate statistically significant differences between the stems and leaves within the sample to Bozokalfa et al. (2011), K was also the most abundant mineral in leaves of Swiss chard (36,850 mg.kg^{-1} DM), followed by Mg (5,420 mg.kg^{-1} DM), Na (3,960 mg.kg^{-1} DM), P (3,550 mg.kg^{-1} DM) and Ca (3,510 mg.kg^{-1} DM). Thovhogi et al. (2023) reported the following concentrations of biogenic elements in Swiss chard (expressed in mg.kg^{-1} dry weight): 1,080–1,530 mg Ca, 370–1,290 mg Mg, and 330–670 mg P. Dzida and Pitura (2008) reported that dry matter of leaves is 6.39–9.23% K, 1.01–1.3% Ca, 0.76–1.19% P and 0.64–0.94% Mg, depending on the fertilization. Kolota et al. (2010) reported that K, Ca, P, and Mg represent 5.17–6.24%, 0.08–0.12%, 0.25–0.40.65%, and 0.49–0.67% of the dry matter of blades respectively, and 5.91–8.43%, 0.11–0.18%, 0.26–0.43%, 0.22–0.43% of the dry matter of petioles respectively depending on the cultivar and term of growing.

The concentrations of essential and potentially toxic elements in Swiss chard stems and leaves revealed distinct distribution patterns between plant parts and sampling sites (Table 2). In both samples, the leaves exhibited significantly higher concentrations of iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) compared to stems, consistent with the role of leaves as metabolically active tissues rich in chloroplasts and involved in nutrient translocation. The highest Fe content was observed in the leaves of Sample 2 (134.9 mg.kg^{-1} DM), while Cu reached an unusually elevated level in Sample 2 leaves (33.6 mg.kg^{-1} DM), potentially indicating localized accumulation or environmental exposure. The accumulation of manganese and zinc was also notably higher in the leaves of Sample 1 (75.7 and 21.0 mg.kg^{-1} DM, respectively). The distribution of chromium (Cr), nickel (Ni), and cobalt (Co) was less variable but showed a slight tendency toward higher concentrations in leaves, particularly in Sample 2. Notably, nickel and cobalt concentrations were elevated in both plant parts of Sample 2, with leaf values reaching 2.20 mg.kg^{-1} (Ni) and 2.36 mg.kg^{-1} (Co), which may reflect environmental conditions or differences in soil composition.

The content of microelements in leafy vegetables, including Swiss chard, is influenced by various factors, notably soil composition, pH, cultivation practices, and environmental stressors. According to Ivanović et al. (2018), the elevated manganese (Mn) levels observed in Swiss chard samples may be attributed to acidic soil conditions or to the secretion of root exudates that enhance Mn bioavailability. Thovhogi et al. (2023) reported the following concentrations of biogenic elements in Swiss chard (expressed in mg.kg^{-1} dry weight): 153.5–381.5 mg Fe, 123.2–488.0 mg Mn, 37.05–56.1 mg Zn.

Regarding toxic metals, the concentration of lead (Pb) varied significantly between samples and tissues. In Sample 1, Pb levels were significantly higher in the leaves (2.59 mg.kg^{-1} DM), while in Sample 2, stems exhibited the highest Pb concentration (2.71 mg.kg^{-1} DM). Cadmium (Cd) content was significantly lower in Sample 1 (≤0.09 mg.kg^{-1} DM), than in Sample 2 (0.20–0.27 mg.kg^{-1} DM). These results underscore the influence of both physiological factors and environmental conditions on elemental accumulation in plant tissues. The observed differences highlight the necessity of monitoring not only the edible parts of the plant but also the cultivation environment to ensure food safety and nutritional quality. Gelaye and Musie (2023) investigated Swiss chard cultivated in three regions of Ethiopia and reported elevated concentrations of lead (Pb) and cadmium (Cd), particularly in samples collected from peri-urban areas. These elevated levels were attributed to soil contamination caused by the intrusion of metal

Table 2 Content of microelements in the analyzed samples (mg.kg^{-1} DM)

Sample	Part	Fe	Mn	Zn	Cu	Co
1	stem	42.3 ±2.5^{a}	33.4 ±1.81^{a}	8.4 ±0.52^{a}	3.9 ±0.21^{a}	0.74 ±0.06^{a}
	leaves	128 ±8.6^{b}	75.7 ±5.55^{b}	21 ±1.31^{b}	7.1 ±0.56^{b}	0.9 ±0.06^{b}
2	stem	100 ±11.1^{a}	38.1 ±2.11^{a}	5.2 ±0.26^{a}	7.0 ±0.47^{a}	0.92 ±0.07^{b}
	leaves	135 ±6.9^{b}	60 ±4.69^{b}	8.4 ±0.39^{b}	33.6 ±1.96^{b}	0.79 ±0.05^{a}

Sample	Part	Ni	Cr	Pb	Cd
1	stem	1.28 ±0.01^{a}	1.67 ±0.10^{a}	1.43 ±0.09^{a}	0.09 ±0.01^{b}
	leaves	1.84 ±0.12^{b}	2.05 ±0.11^{b}	2.59 ±0.15^{b}	0.08 ±0.01^{a}
2	stem	2.24 ±0.11^{a}	2.28 ±0.15^{a}	2.71 ±0.11^{b}	0.27 ±0.01^{b}
	leaves	2.2 ±0.15^{a}	2.36 ±0.14^{a}	1.32 ±0.08^{a}	0.2 ±0.01^{a}

Notes: Different letters indi^c^ate statisti^c^ally signifi^c^ant differen^c^es between the stems and leaves within the sample waste and runoff from nearby industrial zones. The authors emphasized the importance of regular soil monitoring and the implementation of safety measures to ensure that vegetables grown for human consumption do not pose health risks due to heavy metal accumulation. The concentrations of lead (Pb) and cadmium (Cd) in the fresh weight (FW) of Swiss chard tissues were evaluated with comparison to the maximum permissible levels set by the European Commission (0.3 mg.kg^{-1} FW for Pb and 0.2 mg.kg^{-1} FW for Cd) (EC Regulation 2023/915). In Sample 1, Pb concentration in leaves (0.39 ±0.02 mg.kg^{-1} FW) exceeded the regulatory limit, indicating a potential risk for consumer health. In contrast, stems from both samples and leaves from Sample 2 remained within the acceptable Pb threshold, with values ranging from 0.14 to 0.19 mg.kg^{-1} FW. Cadmium concentrations were consistently low across all samples and tissues (0.01–0.02 mg.kg^{-1} FW), remaining well below the regulatory limit. The significantly elevated Pb content in Sample 1 leaves may reflect environmental contamination (e.g., atmospheric deposition or polluted soil), whereas the overall low Cd content indicates minimal exposure to cadmium sources. These results highlight the importance of tissue-specific monitoring of heavy metal contamination in leafy vegetables to ensure compliance with food safety standards.

The mineral content of Swiss chard can vary based on several factors, including soil composition, agricultural practices, and environmental conditions. Understanding these variations is crucial for optimizing cultivation methods to enhance the mineral profile of Swiss chard. Previous studies have indicated that different fertilization and irrigation regimes can influence the concentration of minerals in Swiss chard leaves (Sindesi et al., 2023; Ivanović et al., 2018). Moreover, the levels of key minerals such as phosphorus, magnesium, sodium, and iron exhibit high heritability and genetic advance, suggesting the potential for selective breeding to enhance these traits in future cultivars (Bozokalfa et al., 2014).

The results of this study confirmed that Swiss chard (*Beta vulgaris* L. subsp. *cicla*) is a valuable source of essential macro- and microelements. Notably, significant differences in elemental distribution were observed between plant parts. Leaves accumulated higher concentrations of calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn), whereas stems were comparatively richer in sodium (Na) and potassium (K). These organ-specific differences are nutritionally relevant, as they suggest the potential for targeted utilization of different plant parts in functional or dietary applications. Among the micronutrients, iron and manganese reached the highest concentrations, emphasizing the role of Swiss chard in addressing common mineral deficiencies. Trace elements such as lead (Pb) and cadmium (Cd) were detected in all samples, with particularly elevated levels found in the stems. Although most values remained within the legally permissible limits, the maximum allowable concentration for cadmium was exceeded in the leaves of Sample A. This finding highlights the critical need for regular monitoring of soil quality and irrigation water to ensure the safety of leafy vegetables cultivated for human consumption. Overall, the results underscore the nutritional potential of Swiss chard as a component of a health-promoting diet, while also reinforcing the importance of controlled cultivation practices to minimize the uptake of environmental contaminants.

Total Polyphenol Content and Antioxidant Activity of Swiss Chard

The analysis of total polyphenol content (TPC) and antioxidant activity (AA) in Swiss chard revealed significant differences between plant parts (leaves vs. stems) and between the two samples examined. In both fresh weight (FW) and dry matter (DM) bases, leaves consistently exhibited higher TPC and AA values compared to stems.

For Sample 1, TPC in leaves reached 756 mg GAE.kg^{-1} FW, nearly double the value observed in stems (388 mg GAE.kg^{-1} FW). Antioxidant activity showed

Table 3 Total polyphenol content and antioxidant activity of the analyzed samples

Sample	Part	TPC (mg GAE.kg^{-1} FW)	AA (mmol TE.kg^{-1} FW)	TPC (mg GAE.kg^{-1} DM)	AA (mmol TE.kg^{-1} DM
1	stems	388 ±5.85^a	0.79 ±0.05^a	2,997 ±45.2^a	6.11 ±0.39^a
	leaves	756 ±11.3^b	1.09 ±0.05^b	5,061 ±75.3^b	7.32 ±0.33^b
2	stems	312 ±6.48^a	0.44 ±0.02^a	4,522 ±93.9^a	6.40 ±0.29^a
	leaves	999 ±69^b	1.64 ±0.08^b	9,634 ±665^b	15.9 ±0.77^b

Notes: Different letters indicate statistically significant differences between the stems and leaves within the sample

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only a slight increase in leaves (1.09 mmol TE.kg^{-1} FW) compared to stems (0.79 mmol TE.kg^{-1} FW). In Sample 2, the differences were more pronounced. Leaves displayed markedly higher TPC (999 GAE.kg^{-1} FW) and AA (1.64 mmol TE.kg^{-1} FW) compared to stems (312 GAE.kg^{-1} FW; 0.44 mmol TE.kg^{-1} FW). Pyo et al. (2004) observed that the total phenolic concentration in leaf extracts was significantly higher than in stem extracts, which aligns with the results of the present study. Similar trends have been reported in various studies analyzing the polyphenolic profile of Swiss chard. Libutti et al. (2023) reported 367 mg GAE.kg^{-1} FW, while Moyo et al. (2018) reported a total polyphenol content of 11,040 mg GAE.kg^{-1} DM. Kassahun and Chandravanshi (2025) reported 13,130 mg GAE.kg^{-1} DM in Ethiopian Swiss chard leaves. Olguín-Hernández et al. (2023) reported 4,267.6 mg GAE.kg^{-1} DM in Swiss chard from commercial production, and 4,852.2 mg GAE.kg^{-1} DM in Swiss chard from the ecological production. Higher values of TPC were documented by Mehić and Kazazić (2021), (28,600–34,470 GAE.kg^{-1} DM), and Gawlik-Dziki et al. (2020) (8,940 mg GAE.kg^{-1} FW), likely reflecting differences in extraction methods, plant ecotypes, and environmental conditions. Antioxidant activity values reported in the literature also show variability depending on geographic origin and cultivation practices.

Ivanović et al. (2021) reported antioxidant activity in the range of 6.29–7.54 mmol TE.kg^{-1} DM in Swiss chard grown in Montenegro, depending on the interaction between fertilization and irrigation regimes. Comparable results were published by Tiveron et al. (2012), who measured an antioxidant activity of 9.1 mmol TE.kg^{-1} DM in Swiss chard cultivated in Brazil. Olguín-Hernández et al. (2023) reported lower values: 0.55 mmol TE.kg^{-1} DM in Swiss chard from commercial production, and 1.09 mmol TE.kg^{-1} DM in Swiss chard from the ecological production. These findings support the conclusion that both environmental factors and agricultural practices have a considerable impact on the antioxidant potential and polyphenolic composition of Swiss chard.

The findings of this study confirmed that Swiss chard is a valuable source of polyphenolic compounds and natural antioxidants, with marked differences observed between leaves and stems. In both analyzed samples, the leaves exhibited significantly higher total polyphenol content (TPC) and antioxidant activity (AA) compared to the stems, supporting the premise that leaves are the primary site of bioactive compound accumulation. These differences are nutritionally and functionally significant, indicating that leaf tissues are more suitable for applications aimed at enhancing antioxidant intake in the human diet. Moreover, substantial variation in TPC and AA between the two Swiss chard samples suggests that genotype and environmental conditions, such as soil composition, light exposure, and cultivation practices, play a critical role in determining the bioactive profile of the plant. Overall, the results demonstrate the high potential of Swiss chard, particularly its leaves, as a functional food ingredient with health-promoting antioxidant properties. However, optimizing growing conditions and selecting suitable genotypes are essential strategies for maximizing the accumulation of bioactive compounds in Swiss chard.

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Conclusions

This study highlights the nutritional potential of *Beta vulgaris* as a rich source of essential minerals, polyphenolic compounds, and antioxidants. Significant differences in the accumulation of minerals and bioactive compounds were observed between plant parts, with leaves exhibiting markedly higher levels of total polyphenols and antioxidant activity compared to stems. Higher concentrations of calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn) were detected in the leaves, whereas the stems contained greater amounts of sodium (Na) and potassium (K). Notably, the composition varied not only between leaves and stems but also between the two analyzed samples, suggesting the influence of genetic and environmental factors. The presence of risk elements such as lead and cadmium, especially the exceedance of cadmium limits in one leaf sample, underscores the importance of regular monitoring of cultivation conditions, including soil and irrigation water quality. Overall, Swiss chard demonstrates considerable promise as a functional food ingredient; however, its safety and nutritional quality depend on careful control of the growing environment. These findings support the targeted use of Swiss chard in health-promoting diets and food formulations, particularly when grown under optimized and controlled agroecological conditions.

Conflicts of Interest

The authors have no competing interests to declare.

Ethical Statement

This article does not include any studies that would require an ethical statement.

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