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The Effect of Various Foliar Treatments and Nitrogen Nutrition Levels on the Yield and Physicochemical Parameters of Flowering Chinese Cabbage

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Abstract: Flowering Chinese cabbage (*Brassica campestris* L. ssp. *chinensis* var. *utilis* Tsen et Lee) is an original leafy vegetable from China, and it is a valuable source of bioactive compounds. In the literature, there are no practical recommendations for the cultivation and fertilization of this species. Our study aimed to investigate the effect of nitrogen nutrition levels (70 and 90 mg N per dm^3) and various foliar treatments (Se, Si, Li, V, and SA—salicylic acid) on the quantity of the yield and the quality of flowering Chinese cabbage grown in two varied soilless cultivation systems: under pot cultivation (mixture of peat and sand) and hydroponic culture. In conducted studies, we have confirmed the hypothesis that the intensity of nitrogen nutrition and the application of foliar spraying modify the yield of plants, both the quantity and the quality aspects. The factors under analysis had a diversified and multidirectional influence on the yield, growth, and quality of the plants. The results varied between the two cultivation systems. This was proved by the PCA (principal component analysis). Generally, the plants grown in the hydroponic system were characterized by higher yields than those grown in pot cultivation. This was found to be a stimulating effect of N nutrition on the content of that nutrient in the aerial parts of the plants. Plants sprayed with Si and Se were characterized by a high content of Chl *a*, Chl *b*, carotenoids, and relatively high antioxidant activity. Finally, the samples subjected to different foliar spray treatments could be classified into appropriate groups based on the quality parameters.

Keywords: antioxidant activity; foliar treatment; flowering Chinese cabbage; lithium; nutritional value; salicylic acid; selenium; silicon; vanadium; yield

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1. Introduction

Numerous studies have proved that nitrogen significantly influences the yield and nutritional value of plants due to its key role as a component of amino acids and its effect on the formation of plant proteins and enzymes [1,2]. The world demand for nitrogen for fertilizer use in 2021 was 1.10×10^8 t, and this level would be maintained in 2022 by expectation [3]. However, excessive N fertilization causes environmental problems and contaminates groundwater [4]. Therefore, it is necessary to study how the soil N level affects plants to find its optimum dose.

For many years, foliar treatment has been used in agriculture to improve the yield of crops, increase the efficiency of nutrients, prevent soil salinization, reduce soil fertilization, and thus improve the soil environment [5]. Nutrients/elements can be absorbed directly via leaf stomata and through hydrophilic pores in the leaf cuticle and then transported to other parts of the plant. The main advantage of this fortification is a quicker response

of the plant than in soil fertilization [6]. Moreover, in foliar fertilization, nutrients are sprayed under optimal conditions (time and concentration) for a particular crop, which may result in a synergistic effect [5]. However, the leaf area should be relatively large, or foliar fertilization will not be as effective as soil fertilization [6].

Five different foliar spray treatments were compared in our study, i.e., selenium (Se), silicon (Si), lithium (Li), vanadium (V), and salicylic acid (SA), which represent three types of foliar treatments: metalloid nutrients (Se, Si), metal nutrients (Li, V), and plant hormone (SA). Selenium stimulates plant growth, regulates their antioxidative defence system (enzymatic and non-enzymatic), and thus reduces their susceptibility to UV irradiation, drought stress, and heavy metal-induced stress [7–9]. Nawaz et al. [8] observed that the foliar application of Se-to-wheat exposed to drought stress influenced its yield and nutrient uptake and improved the activity of the antioxidative enzyme system. The Se foliar spray treatment also increased the chlorophyll and carotenoid content in the leaves of *Lycium chinense* L. [9] and *Spinacia oleracea* L. [10]. Se and Si synergistically alleviated the toxicity of cadmium in the shoots of rice plants by transferring more Cd distributed in the cell wall and organelles [7]. Se, combined with Si, markedly stimulated the efficiency of the AsA-GSH cycle by increasing the concentration of glutathione (GSH) and ascorbate (AsA), as well as the activities of glutathione reductase (GR) and dehydroascorbate reductase (DHAR) in the leaves and roots of flowering Chinese cabbage [11]. Independently, the Si fertilizer not only significantly improved the yield of pakchoi (*Brassica chinensis* L.) [12] but was also used for the Si biofortification of leafy vegetables [13].

Li and V treatments exhibit both beneficial properties and toxicity. The final concentration of these elements in plants strongly depends on the concentration of metals in soil, the pH, the redox status of the soil, and the type of plant [14,15]. Both metals can be very harmful to humans, cause impulsiveness and aggressiveness, lead to homicides and suicides (Li), disorder the thyroid and renal functions, induce diarrhoea, cause haematological disturbances, and even lead to death (V). However, they can also stimulate plant growth (Li and V) and metabolism (Li) [14,15]. Zhao et al. [16] found that the foliar treatment of grapes with Li biofortified the berries, especially the skin, with this metal. The Li fertilizer increased the yield of Luobuma tea (*Apocynum venetum*) without reducing the total flavonoid content (TFC) and the antioxidant activity [14]. Even though Li can stimulate plant growth, it may also inhibit it by interrupting numerous physiological processes and altering plant metabolism [17,18]. The V foliar treatment significantly increased the height of sugarcane [19]. Nevertheless, although tobacco (*Nicotiana tabacum* L.) was relatively tolerant to a V concentration of over 2.0 mg dm^{-3} in a hydroponic experiment, its growth was inhibited [20]. SA is a type of hormone normally produced by plants in very small quantities in order to regulate their growth, flowering, and photosynthesis [21]. Therefore, an exogenous foliar SA treatment could have a similar influence. Fariduddin et al. [22] found that the foliar treatment of *Brassica juncea* with an SA spray at a lower concentration substantially enhanced the dry matter content but a higher SA level had an adverse, inhibitory effect.

Flowering Chinese cabbage (*Brassica campestris* L. ssp. *chinensis* var. *utilis* Tsen et Lee) is an original leafy vegetable from China. It is also known as 'Caixin' in Mandarin Chinese and 'Choysum' in the Cantonese dialect. This vegetable is widespread in China and Southeast Asia. Therefore, researchers are increasingly interested in it. Flowering Chinese cabbage is a valuable source of bioactive compounds. It contains glucosinolates (50–70 mg 100 g^{-1}), flavonoids (1.73 mg g^{-1}), rutin (0.14 mg g^{-1}), and vitamin C (52.16 mg 100 g^{-1}) [23,24]. Flowering Chinese cabbage can strongly absorb selenium and so can be used for biofortification [25]. There have only been a few studies on the influence of foliar spray treatments on the yield and quality of flowering Chinese cabbage.

There are no practical recommendations for the cultivation of this species. The research hypothesis put forward assumed that the level of nitrogen nutrition and the application of foliar spraying modify the yield of plants, both the quantity and quality, plant growth, their chemical composition (e.g., chlorophyll, carotenoinds, etc.), and the antioxidant activity.

The hypothesis was tested in two independent systems of plant cultivation: in the substrate and in hydroponics.

2. Materials and Methods

2.1. Experiment Design and Plant Cultivation

Between May and July 2020, two independent greenhouse experiments were conducted at the Marcelin Experimental Station, Poznań University of Life Sciences, Poland, on plants grown in pots with a substrate (I) (a mixture of mineral soil and peat) and in a hydroponic system (II). Studies were conducted with the purple variety of flowering Chinese cabbage (*Brassica campestris* L. ssp. *chinensis* var. *utilis* Tsen et Lee) (Hubei Wuhan Hongshan Caitai Cultivation Center).

Both experiments were conducted in a randomized design, with eight replications in the hydroponic system experiment and ten replications in the pot cultivation (a replication was one plant). The greenhouse was equipped with a climate control system. Throughout the experiment, the ambient temperature was 20–24 °C, and relative humidity was 70–80%. The plants were grown under different conditions of nitrogen nutrition, i.e., 70 and 90 mg N dm^{-3} of growing medium (both in substrate and in nutrient solution, hereinafter referred to as N-70 and N-90). The source of nitrogen was ammonium nitrate (34% N).

Seedlings were prepared 2.5 weeks before the experiment. At the phase of 3–4 leaves, seedlings—in case of pot cultivation—were transplanted into pots filled with a mixture of mineral soil and peat. In the hydroponic system, seedlings were transplanted into Rockwool blocks hydrated with the nutrient solution (Grodan, 100 × 100 × 65 mm). Ten days later, the plants were transplanted into the hydroponic system and, when the root system was well-developed, into Rockwool blocks.

The pot experiment (I) was conducted on plants grown in pots (5 dm^3) filled with a mixture of mineral soil (loamy sand) and peat ($v/v/1/1$) with the following chemical composition (mg dm^{-3}): P—150, K—200, Ca—1500, Mg—200, Fe—75, Mn—25, Zn—20, Cu—10 and pH 6.0–6.5. The hydroponic experiment (II) was conducted on plants grown in a special hydroponic system with recirculation of the nutrient solution (NS). The nutrient solution for fertigation had the following chemical composition (mg dm^{-3}): K—150, P-PO_4—50, K—200, Ca—120, Mg—60, S-SO_4—95, Fe—1.20, Mn—0.5, Zn—0.19, Cu—0.01, B—0.011, and EC (electrolytic conductivity)—2.20 mS cm^{-1}.

A foliar spray treatment (20 mL per plant) was applied three times in both experiments: 18, 23, and 28 days after the transplantation. The plants were treated with different chemicals: silicon (0.2% solution) in the form of choline-stabilized orthosilicic acid (ch-OSA); 0.6% Si; Actisil, Yara, Poland. ch-OSA was obtained from Bio Minerals N.V., Destelbergen, Belgium); selenium (0.005% solution) in the form of sodium selenite (Na_2SeO_4); lithium (0.005% solution) in the form of lithium chlorine ($LiCl \cdot H_2O$); vanadium (0.005% solution) in the form of ammonium vanadate (NH_4VO_3); and salicylic acid (0.04% solution) in the form of $C_7H_6O_3$ (Sigma-Aldrich, USA). The leaves of the control plants were sprayed with distilled water.

2.2. Analysis of Macro- and Microelements in Plants

Flowering Chinese cabbage was harvested on 3 July 2020. All analyses were conducted on the aerial parts of the plants. Samples were dried for 48 h at 45–50 °C to a stable mass and then ground. Before mineralization, the plant material was dried for 1 h at 105 °C. In order to determine the total content of N, P, K, Ca, Mg, and Na, the plant material (1 g) was digested in concentrated (96%, analytically pure) sulphuric acid (20 cm^3) with hydrogen peroxide (30%, analytically pure) [26]. For analyses of the total Fe, Mn, Zn, and Cu content, the plant material (2.5 g) was digested in a mixture of concentrated nitric (ultra-pure) and perchloric acids (analytically pure) at a 3:1 ratio (30 cm^3). After mineralization, the following measurements were taken: total N—the Kjeldahl distillation method in a Parnas Wagner apparatus, P—colourimetry with ammonia molybdate, K, Ca, Mg, Na, Fe, Mn, Zn, and Cu—flame atomic absorption spectroscopy (FAAS) on a Carl Zeiss Jena 5

apparatus (Thornwood, NY, USA). The accuracy of the methods used for the chemical analyses and the precision of analytical measurements of nutrient levels was tested by analysing the reference material of branched flour (*Pseudevernia furfuracea*), certified by the IRMM (Institute for Reference Materials and Measurements) in Belgium [27]. The procedure was also verified with the LGC7162 reference material (LGC standards), with an average nutrient recovery of 96% (N, P, K, Ca, Mg, Fe, Mn, Zn).

2.3. Preparation of Samples for Physicochemical Analyses

A total of 150 g of fresh flowering Chinese cabbage from each combination was freeze-dried at −59 °C (FreeZone, LANCONCO), then ground and stored in a freezer (−18 °C) until analysis. The following parameters were analysed: colour measurements, chlorophyll (Chl) and carotenoid content, total phenolic content (TPC), total flavonoid content (TFC), the antioxidant activity measured as the $ABTS^{\bullet+}$ and $DPPH^{\bullet}$ radical scavenging capacities, and ferrous ion chelating ability (FRAP).

2.4. Colour Measurements

Colour measurements were conducted on freeze-dried powdered samples by means of a CM-5 spectrophotometer (Konica Minolta, Wrocław, Poland). Before each start-up, the device was fully calibrated automatically with an internal white plate to maintain the accuracy of measurements. Zero calibration was carried out manually by placing the CM-A124 zero calibration box on the measuring port. All measurements were taken at a 10° angle of the observer using D65 as a source light. Colours were described in terms of L* (lightness), a* (red/green), and b* (yellow/blue) colour space values according to the C.I.E. 1976 standard of chromatic coordinates. The chroma (C*) and hue angle (h*) were also measured. The mean value of three replications was calculated.

2.5. Chlorophyll a (Chl a), Chlorophyll b (Chl b) and Carotenoid Content

A total of 0.125 g of freeze-dried flowering Chinese cabbage was mixed with 5 mL of methanol for five minutes with a magnetic stirrer and then filtrated into a plastic tube. 80 µL of the eluate was pipetted directly into a cuvette. Then, 3.92 mL of methanol was added and mixed. The green colour sample solution was scanned with a Cary 1E UV/Vis spectrophotometer (Varian, Belrose, Australia) at wavelengths ranging from 410 nm to 700 nm. The baseline scan was made with pure methanol. The contents of Chl *a*, Chl *b*, and carotenoids were calculated from the equation [28] using absorbance values of 665 nm, 652 nm, and 470 nm.

2.6. TPC and TFC Measurements

Folin–Ciocalteu reagent (FCR) was used to measure the total polyphenol content (TPC) according to the procedure described by Singleton and Rossi [29] with some modifications. Briefly, 0.125 g of a freeze-dried flowering Chinese cabbage sample was mixed with 5 mL of distilled water for 30 min. The extract solution was obtained after filtrating the mixed sample solution. Then, 20 µL of the extract was added to 100 µL of FCR in a 2 mL microtube and mixed. After incubation for 3 min at ambient temperature in darkness, 300 µL of 20% (*w*/*v*) sodium carbonate solution was added and the solution was filled up to 2 mL with distilled water. The sample was mixed again and incubated at room temperature for 2 h in darkness. The absorbance of the sample was read at 765 nm with a Cary 1E spectrophotometer against blank samples (40 µL of distilled water instead of extract). There were three replications in each combination. The results were expressed as mg of gallic acid equivalents (GAE) per g of sample.

The following procedure was applied to analyse the TFC. 100 µL of the extract was put into a 1.5-mL microtube. Then, 900 µL of $AlCl_3$ (2% in methanol) was added and mixed. The sample was left in darkness at room temperature for 15 min before reading with a Cary 1E UV/Vis spectrophotometer at 410 nm. The results were expressed as mg quercetin equivalent (QE) per g of sample.

2.7. Antioxidant Activity

The antioxidant activity of flowering Chinese cabbage was measured with three methods, namely, TEAC (Trolox equivalent antioxidant capacity), DPPH (2,2-diphenyl-1-picrylhydrazyl), based on the radical scavenging mechanism, and FRAP (ferric reducing antioxidant power), based on the metal-chelating mechanism.

The TEAC method used in this experiment was based on the modified method developed by Re et al. [30]. Briefly, 0.25 g of powdered freeze-dried flowering Chinese cabbage was extracted with 5 mL of 99% methanol for 30 min and filtrated. The $ABTS^{\bullet+}$ (2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid)) cation radicals were generated in potassium persulphate ($K_2S_2O_8$) during 12–16 hour incubation. This reagent was stable for several weeks when stored in darkness [31]. Then, the $ABTS^{\bullet+}$ solution was mixed with PBS buffer (pH 7.4) freshly prepared on the day of the analysis in order to obtain the final absorbance of 0.7. Next, 10 µL of the extract was added to 990 µL of $ABTS^{\bullet+}$ in PBS and mixed. The absorbance was measured at 734 nm after 6-min incubation at ambient temperature in darkness. The results were expressed as TEAC (Trolox equivalent antioxidant capacity) values in µmol g^{-1} of the dried sample.

The procedure developed by Sánchez-Moreno et al. [32] with some modifications was used for the DPPH assay. Briefly, 10 µL of the extract was added to 990 µL of DPPH in methanol (0.1 mmol) and mixed. The reaction mixture was incubated in darkness at room temperature for 30 min. Next, the decrease in the absorbance caused by the sample was measured at 515 nm against the blank (pure methanol) with a Cary 1E spectrophotometer. The $DPPH^{\bullet}$ radical scavenging activity of the sample was expressed as µmol of Trolox equivalent (TE)/g of flowering Chinese cabbage.

The FRAP method is based on the reduction of Fe^{3+}-tripyridyl-trazine (TPTZ) to a ferrous form by the antioxidant [33]. Briefly, 50 µL of the extract was added to 950 µL of TPTZ working solution and mixed. The TPTZ solution was prepared on the day of analysis. The absorbance was measured at 593 nm after incubation of the sample for 15 min. The results were expressed as mmol TE g^{-1} of the sample.

2.8. Statistical Analysis

The data were analysed with the Statistica 13.3 software (StatSoft Inc., Tulsa, OK, USA). The results of chemical analyses and plant yield measurements were subjected to ANOVA. There were 10 replications of the plants grown in the substrate and 8 replications of the plants grown in the hydroponic system. All other tests were conducted in triplicate. The multiple comparisons were based on the Duncan test ($\alpha = 0.05$) to determine significant differences between the samples. Multivariate analyses were applied in order to obtain more insight into the data matrix. Principal component analysis (PCA) was used as the first step of data analysis to investigate patterns between the variables. Linear discriminant analysis (LDA) was applied to calculate the rules for sample classification.

3. Results

3.1. Yield

The yield of flowering Chinese cabbage grown both in the pot cultivation and in the hydroponic system was significantly influenced by different foliar spray treatments and nitrogen nutrition (Table 1, Figure 1). Generally, the plants grown in the hydroponic were characterized by higher yield than those grown in the substrate. The increasing nitrogen nutrition in both experiments improved the yield of the aerial parts of plants. The foliar spray treatment had different effects on the yield, depending on the N level and the type of cultivation.

Table 1. The yielding of flowering Chinese cabbage grown in pot culture (I) and hydroponic (II) with different N level and foliar spraying (g· of fresh matter per plant).

Foliar Spray	Pot Cultivation			Hydroponic		
	N-70 *	N-90 *	Mean **	N-70	N-90	Mean
Se	118.9 ^{fg}	150.0 ^{bcd}	134.8 ^{c}	163.8 ^{bc}	190.1 ^{abc}	176.9 ^{b}
Si	126.9 ^{efg}	146.9 ^{cd}	136.9 ^{c}	139.6 ^{c}	187.3 ^{abc}	163.4 ^{b}
Li	160.1 ^{bc}	182.0 ^{a}	171.1 ^{a}	157.9 ^{bc}	189.9 ^{abc}	173.9 ^{b}
V	134.8 ^{def}	168.3 ^{ab}	151.6 ^{b}	167.1 ^{bc}	166.3 ^{bc}	166.7 ^{b}
SA	113.6 ^{g}	143.3 ^{cde}	128.5 ^{c}	176.3 ^{abc}	200.6 ^{ab}	188.4 ^{ab}
Control	152.0 ^{bcd}	154.9 ^{bc}	153.5 ^{b}	200.6 ^{ab}	222.3 ^{a}	211.5 ^{a}
Mean **	134.4 ^{b}	157.7 ^{a}		167.5 ^{b}	192.8 ^{a}	
±SD	±16.8	±13.5		±18.5	±16.7	

For all the tables: * Values with the same letter within column nitrogen level N-70 and N-90 (mg dm^{-3}) are not different ($p > 0.05$, Duncan's test). ** Mean value for all the treatment in column, with the same letter within column and raw are not different ($p > 0.05$, Duncan's test). Details of SD (Standard Deviation) were shown in Supplementary Materials (Tables S1–S6).

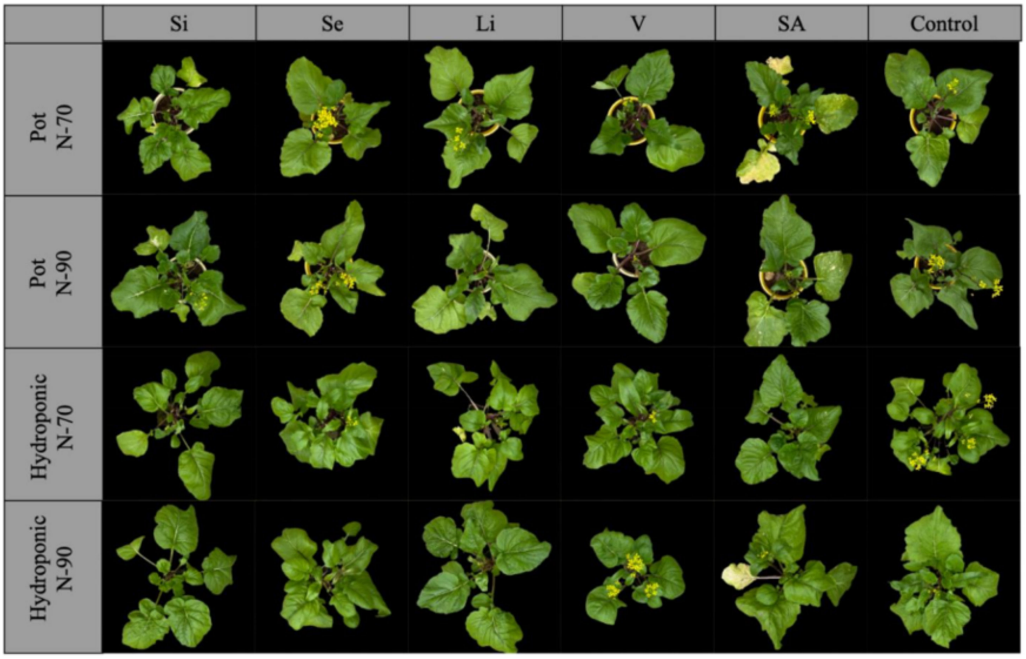

Figure 1. A top view of flowering Chinese cabbage grown in the substrate (pot cultivation) and hydroponically with different foliar treatments and nitrogen levels. The photos were taken at the same height on the day before harvest.

The highest yield (182.0 g of fresh matter per plant) in the pot cultivation was noted at N-90 with the simultaneous Li spray treatment—it was 17.5% higher than the yield of the N-90 plants treated with distilled water (control samples). Moreover, the V treatment at N-90 improved the yield by about 8.5%, as compared with the plants treated with Se, Si, and SA. Generally, there were similar tendencies observed at N-70—the highest yield for the Li spray treatment and the lowest for the Si, Se, and SA. In comparison with the control combination, the Se, Si, and SA treatments reduced the yield by about 21.8%, 17.1%, and 25.7%, respectively. The highest yield in the hydroponic system was noted in the control combination at N-90. However, there were no statistically significant differences between the control and the Si, Se, Li, and SA combinations. In contrast to the substrate cultivation, the V treatment significantly reduced the yield, which was 25.2% lower than in the control combination. At the lower N level, the lowest yield (139.6 g) was noted after the Si treatment (30.5% lower than in the control combination).

3.2. Nutrient Content

The increasing level of nitrogen in the substrate system improved the content of this element in the plants, but the content of macroelements (P, K, Ca, and Mg) did not increase. The highest N content was found in the combinations treated with SA (both at N-70 and N-90), but these combinations were characterized by the lowest yield (Table 2). The foliar spray treatment had a diverse influence on the P content. The influence of the SA treatment on the Mg content depended on the N level. As the N level increased, the Se spray treatment reduced the P content. At N-70, the SA spray treatment decreased the Ca content. The increasing level of N nutrition alleviated this effect and improved the content of Fe, Mn, Zn, and Cu (Table 3). The total mean value showed that the Se, Li, V, and SA spray treatments decreased the Fe content, as compared with the control combination. The increasing level of N nutrition significantly improved the Fe content in the plants treated with Si and SA. There was a similar effect observed for Mn after the SA treatment and in the control combination. According to results from the total mean value, the V, Se, Li, and SA foliar spray treatments decreased the Mn content by 20.36%, 21.23%, 25.69%, and 32.78%, respectively. The V foliar spray treatment increased the Cu content by 25.69%.

The highest N content (5.81%) in the hydroponic system was noted at the N-90 level combined with the simultaneous SA treatment. Generally, according to results from the mean values, the increasing nitrogen nutrition did not change the P, K, Ca, or Mg content in the plants. The Li foliar spray treatment decreased the P content but increased the Na content. The influence of the Si treatment on the Mg content varied depending on the N level. The increasing level of N nutrition improved the mean Fe, Mn, and Cu content in the plants. The Si and Se treatments increased the Fe content. All the foliar treatments decreased the Mn content. At N-90, the Si and Se treatments increased the Zn content, whereas the Li, V, and SA treatments decreased it. The SA foliar spray treatment increased the Cu content, whereas the Li and V treatments decreased it.

3.3. Colour Measurement

The results of the instrumental colour measurement based on the CIE L* (lightness), a* (red/green), and b* (yellow/blue) coordinates are shown in Table 4. Both the N level and the type of foliar spray treatment significantly influenced the colour parameters both in the substrate and hydroponic experiments. The lowest level of lightness was observed in the samples sprayed with SA in both the substrate and hydroponic experiments. The highest lightness was shown for the V-treated sample at N-70 in the substrate and for the Se-treated sample at N-70 in the hydroponic experiment. All the samples were characterized by the green colour (the a* values were below zero).

In substrate, the Li and SA spray treatments resulted in the lowest values of the a* colour parameter at N-70 and N-90, respectively. In comparison with the control sample, at N-70, the V and SA foliar spray treatments decreased the green colour of leaves (increased values of a* parameter when compared to control), whereas, at N-90, the decrease of green colour was caused by the Li and Se treatments. The highest value of the yellow colour (b*) was noted in the control sample at N-70 and in the sample treated with SA at N-90. The Se, Si, V, and Li (only at N-90) foliar spray treatments decreased the value of the b* colour coordinate of the plants, as compared with the control sample. The hue angles of all samples indicated a light green colour (values around 110°) rather than a green colour. In comparison with the control sample, the h* values of the samples treated with SA were lower, whereas the V, Li, Si, and Se treatments increased the hue angle. The chroma value (C*) of the samples that received foliar spray treatments was lower than in the control samples, except the SA-treated sample at N-90.

Table 2. The content of N, P, K, Ca, Mg, and Na in leaves (% of d.m.) of flowering Chinese cabbage grown in pot cultivation and hydroponic.

	N			P			K			Ca			Mg			Na		
Foliar Spray	**N-70 ***	**N-90 ***	**Mean ***	**N-70**	**N-90**	**Mean**	**N-70**	**N-90**	**Mean**	**N-70**	**N-90**	**Mean**	**N-70**	**N-90**	**Mean**	**N-70**	**N-90**	**Mean**
Pot cultivation																		
Se	3.08 ^{f}	3.76 ^{abc}	3.42 ^{bc}	0.50 ^{b}	0.48 ^{b}	0.49 ^{b}	4.21 ^{c}	4.77 ^{abc}	4.49 ^{a}	4.09 ^{a}	3.97 ^{ab}	4.03 ^{a}	0.29 ^{a}	0.28 ^{ab}	0.28 ^{a}	0.14 ^{ab}	0.17 ^{a}	0.15 ^{a}
Si	3.20 ^{ef}	3.73 ^{abcd}	3.47 ^{bc}	0.51 ^{ab}	0.54 ^{ab}	0.53 ^{ab}	4.55 ^{bc}	5.15 ^{a}	4.85 ^{a}	4.02 ^{ab}	3.69 ^{ab}	3.86 ^{a}	0.27 ^{ab}	0.28 ^{ab}	0.28 ^{a}	0.14 ^{ab}	0.17 ^{a}	0.16 ^{a}
Li	3.29 ^{ef}	3.43 ^{cde}	3.36 ^{bc}	0.51 ^{ab}	0.54 ^{ab}	0.52 ^{ab}	4.87 ^{abc}	5.13 ^{ab}	5.00 ^{a}	3.86 ^{ab}	3.89 ^{ab}	3.87 ^{a}	0.26 ^{abc}	0.27 ^{abc}	0.27 ^{ab}	0.13 ^{ab}	0.16 ^{ab}	0.15 ^{ab}
V	3.00 ^{f}	3.52 ^{bcde}	3.29 ^{c}	0.49 ^{b}	0.50 ^{b}	0.50 ^{b}	4.72 ^{abc}	4.67 ^{abc}	4.70 ^{a}	3.60 ^{abc}	2.84 ^{bc}	3.22 ^{ab}	0.26 ^{abc}	0.27 ^{abc}	0.26 ^{ab}	0.15 ^{ab}	0.15 ^{ab}	0.15 ^{ab}
SA	3.83 ^{ab}	3.94 ^{a}	3.89 ^{a}	0.61 ^{a}	0.57 ^{ab}	0.59 ^{a}	4.96 ^{abc}	4.68 ^{abc}	4.82 ^{a}	2.22 ^{c}	3.03 ^{abc}	2.63 ^{b}	0.21 ^{c}	0.25 ^{abc}	0.23 ^{b}	0.13 ^{b}	0.13 ^{ab}	0.13 ^{b}
Control	3.41 ^{ed}	3.71 ^{abcd}	3.56 ^{b}	0.53 ^{ab}	0.50 ^{ab}	0.52 ^{ab}	4.81 ^{abc}	4.82 ^{abc}	4.82 ^{a}	3.26 ^{abc}	3.64 ^{ab}	3.45 ^{ab}	0.25 ^{abc}	0.24 ^{bc}	0.25 ^{ab}	0.14 ^{ab}	0.16 ^{a}	0.15 ^{ab}
Mean **	3.31 ^{b}	3.68 ^{a}		0.53 ^{a}	0.52 ^{a}		4.69 ^{a}	4.87 ^{a}		3.51 ^{a}	3.51 ^{a}		0.26 ^{a}	0.26 ^{a}		0.14 ^{b}	0.16 ^{a}	
±SD	±0.33	±0.19		±0.05	±0.07		±0.51	±0.34		±0.85	±0.83		±0.03	±0.03		±0.02	±0.02	
Hydroponic																		
Se	5.09 ^{d}	5.67 ^{ab}	5.38 ^{ab}	0.42 ^{e}	0.61 ^{a}	0.51 ^{ab}	6.66 ^{a}	6.36 ^{a}	6.51 ^{a}	2.41 ^{abc}	2.59 ^{ab}	2.50 ^{a}	0.78 ^{cd}	0.85 ^{ab}	0.81 ^{ab}	0.18 ^{ab}	0.17 ^{abc}	0.18 ^{ab}
Si	5.04 ^{d}	5.65 ^{abc}	5.34 ^{ab}	0.55 ^{abcde}	0.46 ^{cde}	0.50 ^{ab}	6.27 ^{a}	6.57 ^{a}	6.42 ^{a}	2.30 ^{abc}	2.59 ^{a}	2.44 ^{a}	0.75 ^{bcd}	0.96 ^{a}	0.85 ^{a}	0.16 ^{bc}	0.17 ^{abc}	0.17 ^{ab}
Li	5.25 ^{bcd}	4.97 ^{d}	5.11 ^{b}	0.47 ^{bcde}	0.44 ^{de}	0.45 ^{b}	6.45 ^{a}	6.47 ^{a}	6.46 ^{a}	2.51 ^{abc}	2.57 ^{abc}	2.54 ^{a}	0.85 ^{ab}	0.81 ^{bc}	0.83 ^{ab}	0.19 ^{ab}	0.18 ^{ab}	0.19 ^{a}
V	5.37 ^{bcd}	5.60 ^{abc}	5.48 ^{a}	0.55 ^{abcd}	0.58 ^{abc}	0.57 ^{a}	6.20 ^{a}	6.66 ^{a}	6.43 ^{a}	2.25 ^{abc}	2.19 ^{bc}	2.22 ^{a}	0.81 ^{abc}	0.68 ^{cd}	0.75 ^{abc}	0.20 ^{a}	0.14 ^{c}	0.17 ^{ab}
SA	5.11 ^{d}	5.81 ^{a}	5.46 ^{a}	0.54 ^{abcde}	0.59 ^{ab}	0.57 ^{a}	6.51 ^{a}	6.67 ^{a}	6.59 ^{a}	2.12 ^{c}	2.43 ^{abc}	2.28 ^{a}	0.74 ^{bcd}	0.64 ^{d}	0.69 ^{c}	0.18 ^{ab}	0.16 ^{bc}	0.17 ^{ab}
Control	4.39 ^{e}	5.23 ^{cd}	4.81 ^{c}	0.50 ^{abcde}	0.58 ^{abc}	0.54 ^{a}	6.61 ^{a}	6.57 ^{a}	6.59 ^{a}	2.57 ^{abc}	2.38 ^{abc}	2.48 ^{a}	0.73 ^{bcd}	0.75 ^{bcd}	0.74 ^{bc}	0.17 ^{abc}	0.14 ^{c}	0.16 ^{b}
Mean	5.04 ^{b}	5.49 ^{a}		0.51 ^{a}	0.54 ^{a}		6.45 ^{a}	6.55 ^{a}		2.36 ^{a}	2.46 ^{a}		0.78 ^{a}	0.78 ^{a}		0.18 ^{a}	0.16 ^{b}	
±SD	±0.45	±0.47		±0.07	±0.09		±0.37	±0.40		±0.32	±0.22		±0.10	±0.12		±0.02	±0.02	

Table 3. Fe, Mn, Zn, and Cu content (mg kg^{-1} of dry mass) of flowering Chinese cabbage grown in pot cultivation and hydroponic.

	Fe			Mn			Zn			Cu		
Foliar Spray	**N-70 ***	**N-90 ***	**Mean ****	**N-70**	**N-90**	**Mean**	**N-70**	**N-90**	**Mean**	**N-70**	**N-90**	**Mean**
Pot cultivation												
Se	178.4 ^{bc}	173.5 ^{bc}	175.9 ^{abc}	45.9 ^{bc}	49.0 ^{bc}	47.5 ^{bcd}	72.3 ^{abc}	76.9 ^{ab}	74.6 ^{ab}	5.52 ^{bc}	5.48 ^{bc}	5.50 ^{b}
Si	175.1 ^{bc}	211.9 ^{a}	193.5 ^{a}	51.7 ^{b}	56.5 ^{b}	54.1 ^{ab}	76.3 ^{abc}	76.7 ^{ab}	76.5 ^{ab}	5.07 ^{bc}	5.36 ^{bc}	5.21 ^{b}
Li	164.4 ^{cd}	157.3 ^{cd}	160.9 ^{c}	40.0 ^{cd}	49.9 ^{bc}	45.0 ^{cd}	73.5 ^{abc}	81.1 ^{a}	77.3 ^{a}	5.68 ^{bc}	4.69 ^{c}	5.19 ^{b}
V	173.2 ^{bc}	165.5 ^{cd}	169.4 ^{bc}	47.0 ^{bc}	49.4 ^{bc}	48.2 ^{bc}	71.2 ^{abc}	69.9 ^{abc}	70.6 ^{ab}	5.18 ^{bc}	8.42 ^{a}	6.80 ^{a}
SA	140.3 ^{d}	185.5 ^{abc}	162.9 ^{c}	34.3 ^{d}	47.1 ^{bc}	40.7 ^{d}	64.2 ^{c}	73.4 ^{abc}	68.8 ^{b}	6.37 ^{b}	5.65 ^{bc}	6.01 ^{ab}
Control	181.2 ^{bc}	197.4 ^{ab}	189.3 ^{ab}	50.9 ^{bc}	70.1 ^{a}	60.5 ^{a}	68.9 ^{bc}	77.5 ^{ab}	73.2 ^{ab}	5.63 ^{bc}	5.19 ^{bc}	5.41 ^{b}
Mean **	168.8 ^{b}	181.9 ^{a}		45.00 ^{b}	53.7 ^{a}		71.1 ^{b}	75.9 ^{a}		5.58 ^{a}	5.80 ^{a}	
±SD	±21.0	±22.5		±7.1	±10.1		±6.4	±6.5		±1.02	±1.45	
Hydroponic												
Se	162.7 ^{b}	142.2 ^{bcd}	152.5 ^{b}	41.5 ^{de}	59.8 ^{bc}	50.6 ^{bc}	61.4 ^{ef}	95.6 ^{ab}	78.5 ^{ab}	4.22 ^{cd}	6.31 ^{a}	5.26 ^{ab}
Si	148.0 ^{cb}	193.1 ^{a}	170.5 ^{a}	34.5 ^{ef}	63.8 ^{b}	49.1 ^{c}	70.2 ^{cde}	99.0 ^{a}	84.6 ^{a}	3.74 ^{d}	6.04 ^{ab}	4.89 ^{b}
Li	103.9 ^{f}	114.2 ^{ef}	109.1 ^{c}	45.6 ^{de}	69.0 ^{b}	57.3 ^{b}	76.5 ^{c}	75.0 ^{d}	75.7 ^{b}	3.27 ^{d}	3.70 ^{d}	3.49 ^{c}
V	111.4 ^{ef}	124.0 ^{cdef}	117.7 ^{c}	45.1 ^{de}	49.2 ^{cd}	47.1 ^{cd}	87.8 ^{b}	66.3 ^{def}	77.1 ^{b}	4.21 ^{cd}	3.59 ^{d}	3.90 ^{c}
SA	106.8 ^{ef}	132.0 ^{cde}	119.4 ^{c}	52.1 ^{cd}	28.9 ^{f}	40.5 ^{d}	90.6 ^{ab}	60.4 ^{f}	75.5 ^{b}	5.82 ^{ab}	6.13 ^{a}	5.98 ^{a}
Control	113.7 ^{ef}	119.5 ^{def}	116.6 ^{c}	49.9 ^{cd}	82.5 ^{a}	66.2 ^{a}	91.8 ^{ab}	76.4 ^{c}	84.1 ^{a}	4.99 ^{bc}	4.31 ^{cd}	4.65 ^{b}
Mean	124.4 ^{b}	137.5 ^{a}		44.8 ^{b}	58.9 ^{a}		79.7 ^{a}	78.8 ^{a}		4.38 ^{b}	5.01 ^{a}	
±SD	±25.6	±30.3		±7.2	±8.2		±12.3	±15.3		±0.95	±1.01	

Table 4. Color measurement of flowering Chinese cabbage grown in pot cultivation and hydroponic.

	L* (D65)		a* (D65) Green		b* (D65) Yellow		h* [°] (D65)		C*	
Foliar Spray	**N-70**	**N-90**	**N-70**	**N-90**	**N-70**	**N-90**	**N-70**	**N-90**	**N-70**	**N-90**
Pot cultivation										
Se	49.2 ^{f}	48.5 ^{j}	−8.68 ^{g}	−8.50 ^{c}	22.7 ^{g}	22.0 ^{j}	110.9 ^{c}	111.1 ^{b}	24.3 ^{g}	23.6 ^{j}
Si	49.1 ^{i}	49.1 ^{h}	−8.52 ^{d}	−8.74 ^{h}	21.4 ^{l}	23.0 ^{f}	111.7 ^{a}	110.8 ^{d}	23.0 ^{l}	24.6 ^{f}
Li	49.2 ^{g}	49.6 ^{d}	−9.14 ^{j}	−8.55 ^{e}	23.7 ^{d}	22.5 ^{i}	111.1 ^{b}	110.8 ^{d}	25.4 ^{d}	24.1 ^{i}
V	51.8 ^{a}	49.5 ^{e}	−8.20 ^{a}	−8.64 ^{f}	21.8 ^{k}	22.6 ^{h}	110.6 ^{e}	111.0 ^{c}	23.3 ^{k}	24.2 ^{h}
SA	47.4 ^{l}	47.7 ^{k}	−8.35 ^{b}	−8.83 ^{i}	24.1 ^{c}	24.7 ^{a}	109.1 ^{i}	109.7 ^{g}	25.5 ^{c}	26.2 ^{a}
Control	49.8 ^{c}	50.0 ^{b}	−8.53 ^{d}	−8.63 ^{f}	24.5 ^{b}	23.3 ^{e}	109.2 ^{h}	110.4 ^{f}	25.9 ^{b}	24.8 ^{e}
Mean	49.4	49.1	−8.87	−8.65	23.0	23.0	110.5	110.6	24.6	23.0
±SD	±1.34	±0.79	±0.31	±0.11	±1.18	±0.87	±0.99	±0.48	±1.14	±0.86
Hydroponic										
Se	48.4 ^{a}	47.1 ^{g}	−8.91 ^{l}	−8.37 ^{c}	22.0 ^{d}	20.45 ^{i}	112.0 ^{d}	112.3 ^{b}	23.8 ^{d}	22.1 ^{j}
Si	47.9 ^{c}	48.1 ^{b}	−8.31 ^{b}	−8.31 ^{b}	19.9 ^{j}	20.52 ^{h}	112.7 ^{a}	112.1 ^{c}	21.5 ^{k}	22.1 ^{i}
Li	46.8 ^{h}	47.3 ^{f}	−8.78 ^{i}	−8.56 ^{e}	22.1 ^{c}	20.47 ^{i}	111.6 ^{f}	112.7 ^{a}	23.8 ^{c}	22.2 ^{h}
V	47.6 ^{d}	46.6 ^{i}	−8.58 ^{f}	−8.44 ^{d}	21.2 ^{f}	20.90 ^{g}	112.0 ^{de}	112.0 ^{e}	22.9 ^{e}	22.5 ^{g}
SA	45.3 ^{l}	45.9 ^{k}	−8.83 ^{k}	−8.66 ^{g}	23.5 ^{a}	22.53 ^{b}	110.6 ^{j}	111.0 ^{i}	25.1 ^{a}	24.1 ^{b}
Control	46.5 ^{j}	47.4 ^{e}	−8.81 ^{j}	−8.28 ^{a}	23.5 ^{a}	22.03 ^{e}	110.5 ^{k}	111.3 ^{h}	25.1 ^{a}	22.8 ^{f}
Mean	47.1	47.1	−8.70	−8.44	22.1	21.02	111.6	111.9	23.7	22.7
±SD	±0.92	±0.72	±0.21	±0.14	±1.31	±0.76	±0.81	±0.58	±1.29	±0.73

Note: Three replications were conducted. Means of the parameter with the same superscripts within type of experiment are not different ($p > 0.05$, Duncan's test). L*, lightness; a*, red if "+" and green if "−"; b*, yellow if "+" and blue if "−"; h*, hue angle; C*, chroma; N-70, 70 mg of nitrogen per dm^3 of growing medium; N-90, 90 mg of nitrogen per dm^3 of growing medium; SA, salicylic acid.

In the hydroponic system, the foliar SA treatment resulted in the highest greenness (lowest a* values) and yellowness (highest b* values). The V and Si foliar spray treatments decreased the greenness at N-70, whereas, at N-90, the lowest greenness was observed for the control sample (a* = 8.28). The Se, Si, Li, and V treatments decreased the yellowness, as compared with the control sample.

3.4. Chl a, Chl b, and Carotenoid Content

The content of chlorophylls *a* and *b* and carotenoids (x + c) is shown in Table 5. In the substrate experiment, the content of Chl *a*, Chl *b*, and carotenoid increased along with the increase in the N level (apart from the Li-treated sample). In comparison with the control sample, the Se, Si, Li, and SA foliar spray treatments at N-70 increased the Chl *a* content by 40%, 40%, 21%, and 19%, respectively. At N-90, the Si, Se, and SA foliar spray treatments increased the Chl *a* content by about 26%, 23%, and 12%, respectively, compared with the corresponding control sample. The same pattern (the effect of various foliar sprayings) could be observed for the Chl *b* content. The V foliar spray treatments had different effects on the chlorophyll content; depending on the N dose, it decreased the chlorophyll content or did not change significantly.

All types of the foliar spray treatments increased the carotenoid content at N-70, but only Si, Se, and SA-treated samples increased the carotenoid content at N-90 when compared to the corresponding control. The Chl *a*/Chl *b* weight ratio is an indicator of the functional pigment equipment and light adaptation of the photosynthetic apparatus. Chl *b* is found exclusively in the pigment antenna system, whereas Chl *a* is present in the reaction centres of photosystems I and II and in the pigment antenna. A decrease in the Chl *a*/Chl *b* ratio may be interpreted as an enlargement of the antenna system of PS II. Only the SA-treated sample at N-70 had a lower value of the Chl *a*/Chl *b* ratio (2.83) than the control sample (3.02). All the other combinations of the fertilizer and foliar spray treatments resulted in a higher ratio of Chl *a*/Chl *b*. The weight ratio of Chls *a* and *b* to total carotenoids (Chl *a* + Chl *b*)/(x + c) is an indicator of the greenness of plants. However, there

was no correlation in our study between this index and the a* colour coordinate. The value of this indicator normally ranges from 4.2 to 7.0, depending on the amount of exposure to sunlight. A decrease in the (Chl *a* + Chl *b*)/(x + c) is an indicator of senescence, stress, and damage to the plant and the photosynthetic apparatus, which is expressed by a faster breakdown of Chls than carotenoids. Then, leaves become more yellowish-green and the values of the (Chl *a* + Chl *b*)/(x + c) ratio are 3.5 or even lower. In this study, the value of the (Chl *a* + Chl *b*)/(x + c) ratio for V at N-70 (4.52) was significantly lower than for the control sample (5.22).

Table 5. Chlorophyll (Chl *a* and Chl *b*) and carotenoid (x + c) content (mg g^{-1} DW) of flowering Chinese cabbage grown in pot cultivation and hydroponic.

Foliar Spray	Chl *a* (mg g^{-1} DW)		Chl *b* (mg g^{-1} DW)		Carotenoid (x + c) (mg g^{-1} DW)		Chl *a* + Chl *b* (mg g^{-1} DW)		Chl *a*/Chl *b*		(Chl *a* + Chl *b*)/(x + c)	
	N-70	N-90	N-70	N-90	N-70	N-90	N-70	N-90	N-70	N-90	N-70	N-90
Pot cultivation												
Se	6.86 ^{a}	6.92 ^{a}	2.19 ^{ab}	2.21 ^{ab}	1.76 ^{ab}	1.80 ^{ab}	9.04 ^{a}	9.13 ^{a}	3.13 ^{b}	3.14 ^{b}	5.14 ^{a}	5.08 ^{a}
Si	6.85 ^{a}	7.12 ^{a}	2.20 ^{ab}	2.26 ^{a}	1.71 ^{b}	1.84 ^{a}	9.05 ^{a}	9.38 ^{a}	3.11 ^{b}	3.15 ^{b}	5.29 ^{a}	5.11 ^{a}
Li	5.91 ^{c}	5.04 ^{d}	1.84 ^{cd}	1.65 ^{de}	1.52 ^{cd}	1.34 ^{f}	7.75 ^{c}	6.69 ^{d}	3.21 ^{b}	3.05 ^{bc}	5.10 ^{a}	4.98 ^{ab}
V	4.62 ^{e}	5.75 ^{c}	1.32 ^{f}	1.94 ^{c}	1.33 ^{f}	1.44 ^{de}	5.94 ^{e}	7.69 ^{c}	3.53 ^{a}	2.97 ^{bc}	4.52 ^{b}	5.34 ^{a}
SA	5.81 ^{c}	6.31 ^{b}	2.07 ^{abc}	2.01 ^{bc}	1.49 ^{cd}	1.58 ^{c}	7.88 ^{bc}	8.32 ^{b}	2.83 ^{c}	3.14 ^{b}	5.27 ^{a}	5.27 ^{a}
Control	4.89 ^{ed}	5.63 ^{c}	1.62 ^{e}	1.99 ^{bc}	1.25 ^{g}	1.38 ^{ef}	6.50 ^{d}	7.62 ^{c}	3.02 ^{bc}	2.84 ^{c}	5.22 ^{a}	5.52 ^{a}
Mean	5.82	6.13	1.87	2.01	1.51	1.56	7.70	8.14	3.14	3.05	5.09	5.22
±SD	±0.90	±0.77	±0.36	±0.21	±0.20	±0.20	±1.24	±0.97	±0.26	±0.13	±0.41	±0.23
Hydroponic												
Se	8.24 ^{b}	8.80 ^{a}	1.67 ^{ab}	1.82 ^{a}	2.29 ^{ef}	2.23 ^{f}	9.91 ^{d}	10.62 ^{ab}	4.94 ^{bc}	4.84 ^{bc}	4.33 ^{b}	4.77 ^{a}
Si	9.02 ^{a}	8.47 ^{b}	1.85 ^{a}	1.70 ^{ab}	2.50 ^{ab}	2.39 ^{cde}	10.87 ^{a}	10.17 ^{cd}	4.89 ^{bc}	4.97 ^{bc}	4.35 ^{b}	4.31 ^{b}
Li	8.36 ^{b}	8.91 ^{a}	1.68 ^{ab}	1.73 ^{ab}	2.33 ^{def}	2.55 ^{a}	10.05 ^{cd}	10.64 ^{ab}	4.98 ^{bc}	5.17 ^{bc}	4.31 ^{b}	4.18 ^{bc}
V	8.25 ^{b}	8.36 ^{b}	1.79 ^{a}	1.56 ^{bc}	2.39 ^{bcde}	2.50 ^{ab}	10.04 ^{cd}	9.92 ^{d}	4.62 ^{c}	5.37 ^{b}	4.20 ^{bc}	3.96 ^{c}
SA	7.81 ^{c}	8.43 ^{b}	1.30 ^{d}	1.76 ^{a}	2.48 ^{abc}	2.41 ^{bcd}	9.10 ^{e}	10.19 ^{cd}	6.11 ^{a}	4.81 ^{bc}	3.68 ^{d}	4.23 ^{b}
Control	8.45 ^{b}	6.91 ^{d}	1.85 ^{a}	1.48 ^{c}	2.45 ^{abcd}	2.05 ^{g}	10.30 ^{bc}	8.39 ^{f}	4.58 ^{c}	4.68 ^{c}	4.21 ^{bc}	4.09 ^{bc}
Mean	8.35	8.31	1.69	1.67	2.41	2.35	10.04	9.99	5.02	4.98	4.18	4.26
±SD	±0.38	±0.69	±0.21	±0.15	±0.10	±0.18	±0.56	±0.80	±0.63	±0.34	±0.27	±0.28

Note: Three replications were conducted. Means of the parameter with the same superscripts within type of experiment are not different ($p > 0.05$, Duncan's test). Chl, chlorophyll; N-70, 70 mg of nitrogen per dm^3 of growing medium; N-90, 90 mg of nitrogen per dm^3 of growing medium; SA, salicylic acid.

In the hydroponic experiment, the effect of the N dose was statistically significant only for the carotenoid content. As the N level increased, the carotenoid content decreased. Chlorophylls (Chls) were highly affected only by the type of the foliar spray treatment. The lowest levels of Chls were observed for the SA (N-70) and control (N-90) samples. The highest Chl *a* content was observed after the Si foliar spray treatment at N-70 and the Se and Li treatments at N-90. At N-90, all the foliar treatments increased the Chl *b* and carotenoid content. At N-70, the total carotenoid content was the lowest after the Se treatment. All the foliar treatments resulted in higher values of the Chl *a*/Chl *b* ratio than the control sample. However, the increase was statistically significant only for the SA (N-70) and V (N-90) samples, as compared with the corresponding control samples. The Chl *a*/Chl *b* ratio in the hydroponic experiment was significantly higher than in the substrate experiment. The value of the (Chl *a* + Chl *b*)/(x + c) indicator in the hydroponic experiment was lower than in the substrate experiment, which indicated lower greenness of the hydroponic plants. The SA treatment at N-70 resulted in the lowest value of this indicator, whereas the Se (N-90) treatment resulted in its highest value.

3.5. Total Polyphenol Content and Total Flavonoid Content

The total polyphenol content (TPC) and total flavonoid content (TFC) values are shown in Table 6. In pot cultivation, the N nutrition level did not influence the TPC, but it influenced the TFC—the higher the N level, the lower the TFC values. The plants treated with SA at N-70 had the highest TPC (9.46 mg GAE g^{-1}), which was about 26.30% higher

than in the control sample. The lowest TPC (6.21 mg GAE g^{-1}) was noted after the Si foliar spray treatment at N-90. The lowest TFC was noted after the SA foliar spray treatment at the N-90 level (1.78 mg QE g^{-1}) and the highest after the Se-treated sample at N-70 (2.68 mg QE g^{-1}). The TPC values were significantly correlated with the TFC—the value of the Pearson correlation coefficient was 0.48 (p = 0.003).

Table 6. Antioxidant activity (TEAC, DPPH, FRAP), total phenolic content (TPC), and total flavonoid content (TFC) of flowering Chinese cabbage grown in pot cultivation and hydroponic.

Foliar Spray	TPC (mg GAE g^{-1})		TFC (mg QE g^{-1})		TEAC (μmol g^{-1})		DPPH (μmol TE g^{-1})		FRAP (mmol TE g^{-1})	
	N-70	N-90	N-70	N-90	N-70	N-90	N-70	N-90	N-70	N-90
Pot cultivation										
Se	8.69 ^{c}	8.87 ^{bc}	2.68 ^{a}	2.45 ^{b}	615.4 ^{d}	646.2 ^{b}	184.5 ^{bc}	177.8 ^{ef}	38.7 ^{b}	39.5 ^{a}
Si	9.10 ^{b}	6.21 ^{g}	2.32 ^{bc}	1.94 ^{f}	589.7 ^{f}	647.9 ^{b}	179.0 ^{de}	167.4 ^{h}	38.5 ^{b}	38.8 ^{b}
Li	8.16 ^{d}	8.60 ^{c}	2.16 ^{de}	2.13 ^{de}	576.3 ^{g}	593.1 ^{f}	182.0 ^{cd}	192.4 ^{a}	34.2 ^{e}	34.4 ^{e}
V	6.87 ^{f}	8.67 ^{c}	2.13 ^{de}	2.26 ^{cd}	576.4 ^{g}	606.0 ^{de}	166.2 ^{h}	187.3 ^{b}	29.9 ^{f}	36.3 ^{d}
SA	9.46 ^{a}	8.59 ^{c}	2.35 ^{bc}	1.78 ^{g}	720.4 ^{a}	602.1 ^{ef}	166.2 ^{h}	173.7 ^{g}	36.1 ^{d}	36.7 ^{cd}
Control	7.49 ^{e}	8.62 ^{c}	2.09 ^{e}	2.17 ^{de}	629.8 ^{c}	647.5 ^{b}	175.7 ^{fg}	186.1 ^{b}	34.8 ^{e}	37.1 ^{c}
Mean	8.30	8.26	2.29	2.13	618.0	623.8	175.6	180.8	35.4	37.1
±SD	±0.94	±0.96	±0.22	±0.22	±51.9	±24.6	±7.60	±8.92	±3.08	±1.77
Hydroponic										
Se	7.31 ^{c}	6.66 ^{cde}	1.86 ^{b}	1.58 ^{b}	630.6 ^{a}	614.7 ^{b}	201.3 ^{b}	224.1 ^{a}	44.8 ^{a}	43.0 ^{b}
Si	8.61 ^{b}	6.19 ^{e}	2.03 ^{b}	3.69 ^{a}	607.4 ^{bc}	530.8 ^{g}	195.2 ^{c}	204.5 ^{b}	44.3 ^{a}	35.8 ^{f}
Li	8.38 ^{b}	6.10 ^{e}	2.27 ^{b}	1.66 ^{b}	598.5 ^{c}	552.1 ^{f}	205.9 ^{b}	177.0 ^{e}	39.6 ^{d}	39.3 ^{d}
V	7.17 ^{cd}	8.60 ^{b}	2.57 ^{b}	2.03 ^{b}	607.7 ^{bc}	609.8 ^{bc}	186.0 ^{d}	176.4 ^{e}	41.8 ^{c}	39.6 ^{d}
SA	10.0 ^{a}	6.51 ^{de}	2.17 ^{b}	1.68 ^{b}	549.7 ^{f}	517.6 ^{h}	155.9 ^{f}	108.1 ^{g}	34.5 ^{g}	33.7 ^{h}
Control	8.56 ^{b}	8.03 ^{b}	2.03 ^{b}	2.11 ^{b}	578.7 ^{d}	566.6 ^{e}	183.3 ^{d}	184.1 ^{d}	38.7 ^{e}	34.7 ^{g}
Mean	8.34	7.01	2.15	2.12	595.4	565.3	188.0	179.1	40.6	37.7
±SD	±0.99	±1.06	±0.24	±1.05	±26.78	±38.3	±17.2	±37.0	±3.63	±3.45

Note: Three replications were conducted. Means of the parameter with the same superscripts within type of experiment are not different (p > 0.05, Duncan's test). TPC, total polyphenol content; TFC, total flavonoid content; TEAC, Trolox equivalent antioxidant capacity; DPPH, 1,1′-diphenyl-2-pikryl-hydrazyl; FRAP, ferric reducing antioxidant power; TE, Trolox equivalent; GAE, gallic acid equivalents; QE, quercetin equivalents; N-70, 70 mg of nitrogen per dm^3 of growing medium; N-90, 90 mg of nitrogen per dm^3 of growing medium; SA, salicylic acid.

In the hydroponic experiment, the N level did not influence the TFC, but an increase of N level decreased the TPC. The highest TPC (10.00 mg GAE g^{-1}) was noted after the SA spray treatment at the N-70 level. The lowest TPC (6.10 mg GAE g^{-1}) was measured in the sample treated with Li at the N-90 level. The Si foliar spray treatment increased the TFC compared with the control group at the N-90 dose. The TFC values for Se, Li, V, and SA foliar treatments did not differ from the TFC value of the control. There was no correlation between the TPC and TFC in the hydroponic experiment.

3.6. Antioxidant Activity

As there are various mechanisms of antioxidant activity, three different methods were used in this study. The TEAC (Trolox equivalent antioxidant capacity) and DPPH (1,1′-diphenyl-2-pikryl-hydrazyl) methods correspond to the radical scavenging capacity of the sample, whereas the FRAP (ferric reducing antioxidant power) method is based on the metal-chelating ability of the tested sample. The results of the antioxidant activity of the flowering Chinese cabbage are shown in Table 6.

In the pot experiment, the antioxidant activity was significantly affected by the N nutrition level and the foliar spray treatment. The highest TEAC values of 720 μmol g^{-1} were noted after the SA treatment at the N-70 level, which was 14.38% higher than in the N-70 control group. The Li and V treatments decreased the TEAC values when compared

with control, irrespective of the N dose. In the DPPH assay, the lowest antioxidant activity (166.2 μmol g^{-1}) was noted after the SA and V foliar spray treatments at the N-70 level. The highest activity (192.38 μmol g^{-1}) was noted after the Li spray treatment at the N-90 level. This resulted in a negative value of the Pearson correlation coefficient for the correlation between the DPPH and TEAC assays (r = −0.36, p = 0.031). The highest antioxidant activity measured in the FRAP assay was noted in the Se-treated plants at N-90 (39.54 mmol TE g^{-1}). The FRAP values were significantly correlated with the TEAC values (r = 0.39, p = 0.02). In the substrate experiment, the antioxidant activity measured with the DPPH method was correlated with the TPC (r = 0.42, p = 0.011), whereas the metal chelating ability (FRAP) was significantly correlated with the carotenoid content (r = 0.75, p = 0.00). This indicated that the radical scavenging capacity of the flowering Chinese cabbage was an effect of phenolic compounds, but the metal chelating ability resulted mainly from the carotenoid content.

In the hydroponic experiment, the N level and the type of foliar spray treatment had a statistically significant influence on the antioxidant activity. The Se foliar spray treatment induced the highest antioxidant activity of the flowering Chinese cabbage evaluated by all methods. In comparison with the control group, the mean increase (calculated for both N doses) amounted to about 16% (662.65 μmol g^{-1}), 16% (212.74 μmol g^{-1}), and 29% (43.89 mmol TE g^{-1}) for the TEAC, DPPH, and FRAP assays, respectively. On the contrary, the lowest antioxidant activity was observed after the SA foliar treatment. There were high values of the correlation coefficients for the antioxidant activity, i.e., r = 0.62 for DPPH vs. TEAC, r = 0.62 for DPPH vs. FRAP, and r = 0.87 for FRAP vs. TEAC. The antioxidant activity was correlated neither with the phenolic nor carotenoid content in the hydroponic experiment.

3.7. Multivariate Analysis

Before the analysis, the data matrix was standardized, and the Pearson correlation coefficients were calculated. PCA, an unsupervised pattern recognition method, was applied to find relationships between variables. Using the graphical criterion, the first eight principal components (PCs) were derived with an eigenvalue greater than 1. Together, they explained 87.4% and 85.5% of the total variance in the substrate and hydroponic datasets, respectively. The loaded values showing correlations between the components, and variables indicated that in pot cultivation, the content of chlorophylls and carotenoids, as well as the FRAP and L* values, distributed the samples along the PC1 axis (Figure 2a), whereas the C, h, and b* colour parameters distributed them along the PC2 axis. In the hydroponic experiment, the C, h, b*, and L* colour parameters predominated the PC1, whereas the Mn parameter predominated the PC2 (Figure 2b). The values of the correlation coefficients indicated a strong relationship among the variables shown on the factor plane. As evidenced by the analysis of figures showing the scores on the factor plane (Figure 2a,b), the samples sprayed with Si, Se, or SA were distinguished from others. In the pot cultivation (Figure 2a), Si- and Se-treated plants showed high chelating ability (the FRAP values) and high $DPPH^{\bullet}$ radical scavenging activity at N-70, which could result from high carotenoid and phenolic content. Moreover, Si- and Se-treated samples were shown to contain a high level of chlorophylls. SA-treated plants showed high radical scavenging activity (the TEAC values at n-70) and those samples contained high levels of N and relatively high carotenoid and chlorophyll content in the pot experiment. In the hydroponic experiment (Figure 2b), the SA-sprayed sample was characterized by low antioxidant activity and a relatively high content of carotenoids, but a low content of chlorophylls (the latter at N-70 dose) and high b* value. Se-treated samples showed high antioxidant activity among all samples expressed by the three methods. Moreover, the Si-, Se-, and SA-treated samples exhibited low lightness (the L* value) in pot cultivation, whereas, in the hydroponic experiment, the Si-treated samples exhibited high lightness and SA-treated sample low lightness.

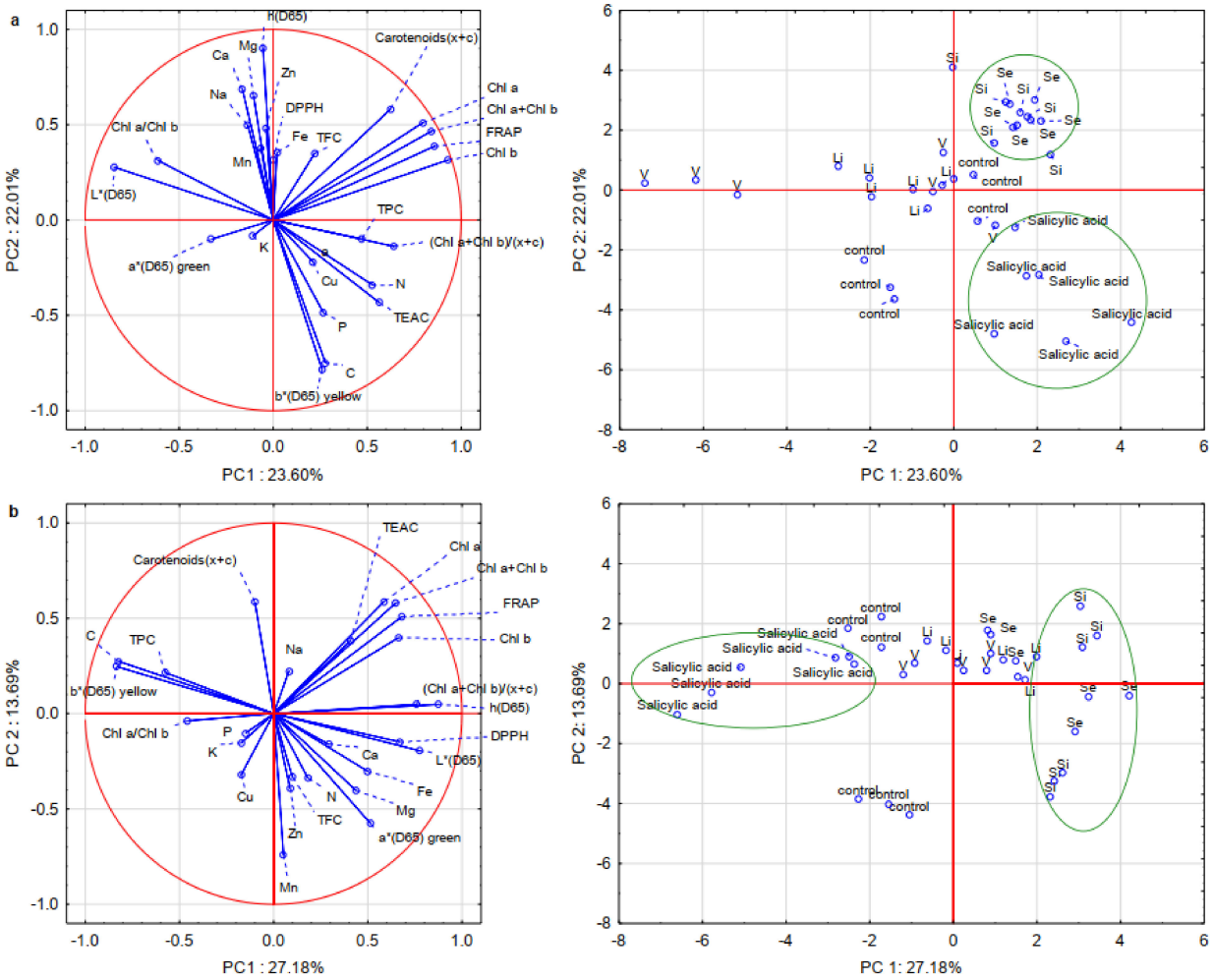

Figure 2. Projections of the variables and scores onto the factor plane defined by principal components (PC1 and PC2) for (**a**) pot cultivation and (**b**) hydroponic experiments.

Next, the PCs obtained in the PCA were used as the input data for the linear discriminant analysis (LDA) to avoid the LDA model overfitting due to the high number of variables. To obtain a satisfactory discrimination ability, the first ten PCs were used for the substrate experiment and the first nine PCs for the hydroponic experiment. This resulted in the highest propriety of classification (100%) in both data matrices. The scatterplot obtained in the LDA resulted in excellent discrimination of the samples sprayed with salicylic acid (SA) and V in the substrate experiment (Figure 3a), as well as the control sample and the SA-sprayed sample in the hydroponic experiment (Figure 3b). The standardized canonical discriminant function coefficients indicated the relative significance of the PCs in the canonical variables (Roots) (Supplementary Materials Tables S7 and S8). The values of chlorophylls, colour, FRAP, and DPPH contributed the most to the first canonical variable (Root 1), which accounted for 61.6% of the total variance in the substrate experiment and 85.4% of the total variance in the hydroponic experiment. This indicated that the parameters had the highest discrimination power. In both experiments, the Si- and Se-treated samples were classified close to each other because they had very similar chlorophyll content, colour coordinates, and FRAP values. Finally, the samples subjected to different foliar spray treatments could be classified into appropriate groups based on the parameters under analysis.

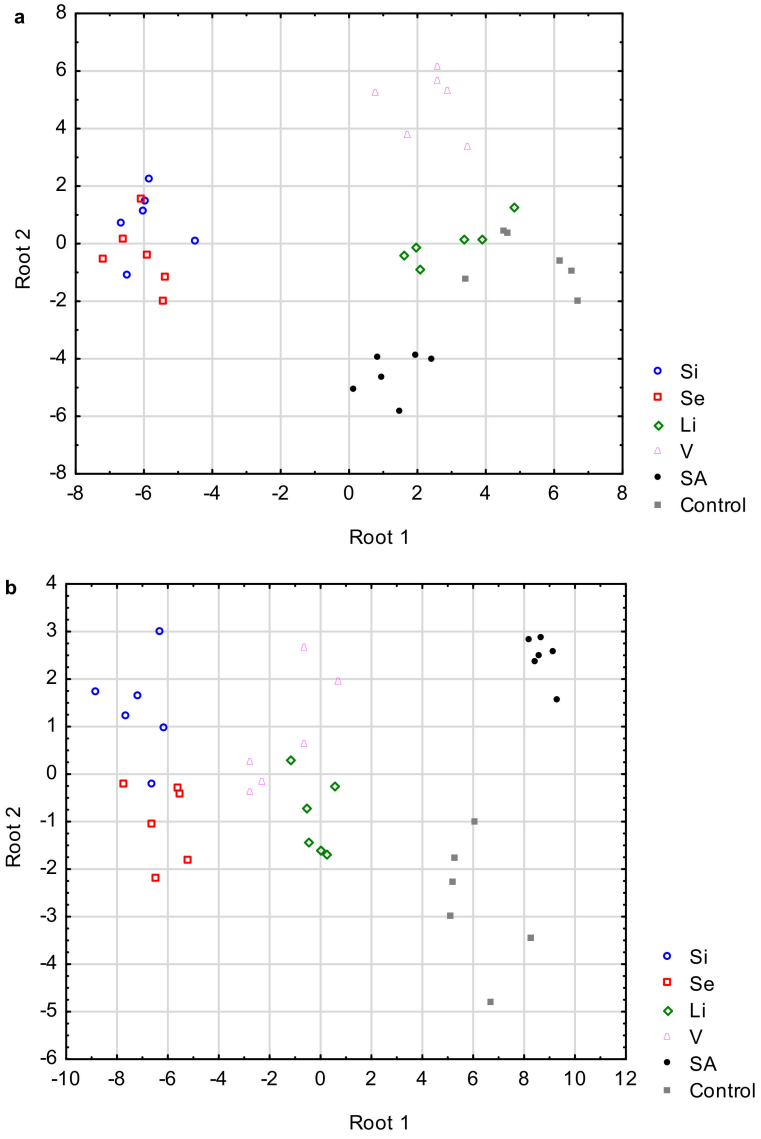

Figure 3. Linear discriminant analysis (LDA) of the samples subjected to various foliar spraying in (**a**) pot cultivation and (**b**) hydroponic experiments.

4. Discussion

4.1. Yielding

Nitrogen is a nutrient with the most significant influence on plants' yield volume. In our study, it also stimulated the yield of flowering Chinese cabbage. Interestingly, the highest mean weight of the plants was found in the combination treated with Li (in the pot cultivation). As evidenced by the mean values, the foliar treatment of the plants grown at N-90 in the hydroponic system decreased their yield. Our findings were consistent with the results of other studies. The nitrogen fertilizer increased the yield of flowering Chinese cabbage by 41.80%, but excessive doses could reduce the yield [34]. Our findings were also consistent with the results of a study on Chinese cabbage conducted by Krężel and Kołota [35], who observed higher head yields when the nitrogen doses increased from 50 to 150 kg N ha^{-1}, but decreased yield at doses of 200 kg N ha^{-1}. Selenium plays a role in plants' mechanisms of antioxidant activity and is a component of glutathione peroxidase [36]. In our study, the Se treatment decreased the yield of the plants by 12.19% in the pot experiment and by 16.34% in the hydroponic experiment. Saffaryazdi et al. [10] observed that the yield of spinach decreased at a higher concentration (>1 mg L^{-1}) of Se applied in a foliar spray treatment. The concentration may differ depending on the plant

species. Some plants tend to accumulate Se and exhibit higher tolerance to this element. A decrease in the yield was observed among non-hyper-accumulator plants because they are more sensitive to Se [37]. The tomato yield increased even when the Se concentration was 10 ppm [38]. Silicon is not considered an essential nutrient for plants because most plant species can complete the life cycle without it. However, many scientists observed the beneficial effect of Si on the nutritional value of vegetables [13]. In our study, the Si treatment decreased the yield volume by 10.79% in the pot experiment and by 22.72% in the hydroponic. D'Imperio et al. [13] did not find the positive effect of Si on the yield and colour of several leaf vegetables, i.e., tatsoi, mizuna, purslane, basil, Swiss chard, and chicory, but the Si foliar spray treatment increased the height of sugarcane [19]. The inhibitory effect of Si observed in our study may have been caused by the different Si tolerance of flowering Chinese cabbage. Lithium is not an essential element for plants, but it can stimulate their growth at relatively low concentrations and inhibit it at higher concentrations [39,40]. In our study, there were differences in the growth of flowering Chinese cabbage between the pot cultivation and hydroponic experiments after the Li treatment. The mean yield volume in the pot experiment was higher (+11.47%), but it decreased (−17.79%) in the hydroponic experiment (in each case compared with control). Likewise, the effect of vanadium on the flowering Chinese cabbage also depended on the type of cultivation. In our experiments, V had no influence on the yield of flowering Chinese cabbage grown in the substrate, regardless of the N level, but it inhibited the growth of the plants in the hydroponic experiment (there were significant differences at N-90). Wu et al. [20] found that the growth of tobacco was not affected by a V concentration of <2 mg L^{-1} applied in a foliar spray treatment, but the plant growth was inhibited at ≥2.0 mg L^{-1}. Plant responses could vary depending on the V concentration. The application of 5 µM V in a hydroponic system increased the growth of pepper plants but caused a toxicity symptom at higher concentrations (10 and 15 µM) [41]. The salicylic acid foliar spray treatment reduced the yield of the flowering Chinese cabbage grown in the pot cultivation substrate at N-70, but this effect was alleviated at the higher N level. The SA treatment did not have a significant influence on the yield of the plants grown in the hydroponic system, regardless of the N level. Mohamed et al. [42] observed that the foliar application of SA at a concentration of 200 ppm to lettuce caused a significant increase in its yield, but a higher SA concentration reduced it. There are not enough scientific publications explaining the effect of SA on flowering Chinese cabbage.

4.2. Plant Nutrient Status

A positive effect of N nutrition was found on the content of that nutrients in plants without significant changes of P, K, Ca, and Mg content. In the case of microelements, a stimulating effect was determined for Fe and Mn independent of type cultivation, as well as Zn (for pot cultivation) and Cu (for hydroponic). The Se treatment decreased the Mn content in the aerial parts of the plants both in the pot and hydroponic experiments, but it increased the content of N and Fe in the plants grown hydroponically. Our research findings were comparable with the results of the study conducted by Nawaz et al. [8], who found that the Se treatment had a significant effect on the Fe content in wheat shoots. They observed a greater increase in the plants exposed to drought stress than in those that were not exposed to the stress. The Si foliar spray treatment increased the leaf N, Mg, and Fe content in the plants grown in the hydroponic experiment but decreased the Mn content. In our study, the Li foliar spray treatment decreased the content of Fe and Mn in the plants grown in the pot cultivation. It also decreased the content of N, Mn, and Zn in the plants grown in the hydroponic experiment. Lithium shares the transport of potassium in roots [43]. Therefore, the content of K might be influenced by the Li application. In our study, this phenomenon was not observed. The V foliar spray treatment significantly reduced the content of N and Mn in the leaves of the plants grown in the pot cultivation and simultaneously increased the Cu content. There were similar effects observed in the hydroponic experiment. The V treatment reduced the content of most of

the metallic microelements (Mn, Zn, and Cu) and simultaneously increased the N content. Other researchers also observed a decrease in the Mn content in their studies [41,44]. The possible cause of this effect might be the antagonism between V as a metal and a metallic micronutrient. In our study, the SA spray treatment decreased the content of Ca, Mg, Fe, and Mn in the plants grown in the substrate. The transport of SA in plant cells, tissues, and organs was finely regulated by ROS and Ca^{2+} [45]. Therefore, it may have been the reason why the Ca content in the leaves of flowering Chinese cabbage decreased.

4.3. Pigments

In our study, the Se foliar spray treatment improved the levels of chlorophyll *a*, chlorophyll *b*, and carotenoids both in the pot and hydroponic experiments (the latter at N-90 dose). The colour measurements also showed that the Se treatment reduced the lightness and yellow colour but resulted in a relatively high green colour. Aly and Abdel-Halim [38] observed that the pigment in potato leaves increased significantly after the Se foliar spray treatment. Dong et al. [9] also found that the Se foliar spray treatment of *Lycium chinense* L. increased the content of chlorophyll and carotenoids by 200–400%. The increase in the chlorophyll content is likely to have been caused by the fact that Se protects chloroplast enzymes and consequently increases the biosynthesis of photosynthetic pigments [46]. The effect of the Si treatment on the colour, as well as the content of chlorophyll and carotenoids in the flowering Chinese cabbage, was similar to the effect of Se. The Li treatment increased the chlorophylls and carotenoid content in the pot experiment at N-70. The Li foliar spray treatment also increased the content of Chl *a* and *b*, as well as carotenoids (the latter only at N-90 dose) in the hydroponic experiment. Hawrylak-Nowak et al. [39] found that the Li treatment did not significantly influence the content of chlorophylls *a* and *b* or carotenoids in sunflower plants. However, a lithium concentration of 50 mg dm^{-3} significantly decreased the content of all pigments in maize.

In our study, the V foliar spray treatment increased the content of carotenoids in the pot experiment and in the hydroponic experiment at N-90, whereas it had no effect or only a slight effect on the chlorophyll content. The colour measurements (at N-70) showed that the treatment increased the lightness (L*) and green colour (a*) of the leaves but decreased the yellow colour (b*). An increase in the chlorophyll content was also observed in maize [47] and potato leaves [48] after V foliar spray treatment. The effect of vanadium might be intensified by the Hill reaction occurring in the chloroplasts, which accelerates photosynthesis and plant development [48].

The SA treatment did not influence the green colour of the sample. The treatment increased the content of Chl *a*, Chl *b*, and carotenoids in the pot experiment and carotenoids in the hydroponic experiment. Fariduddin et al. [22] conducted an experiment on *Brassica juncea* and observed that when the plants were sprayed with SA at lower concentrations (10^{-5} M), the chlorophyll content increased significantly, whereas higher SA concentrations proved to be inhibitory.

4.4. Antioxidant Activity

The ABTS, DPPH, and FRAP assays accordantly showed that the Se foliar spray treatment improved the antioxidant activity of the flowering Chinese cabbage leaves in our experiment. It also increased the TPC and TFC in the pot experiment. Se may act as a pro-oxidant reducing the yield, but it also stimulated the antioxidative function of flowering Chinese cabbage. Saffaryazdi et al. [10] observed that Se increased the activity of antioxidant enzymes such as peroxidase and polyphenol oxidase, as well as the TPC and TFC. Wu et al. [11] conducted a study on flowering Chinese cabbage and found that the Se foliar spray treatment increased the activity of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), glutathione reductase (GR), and dehydroascorbate reductase (DHAR).

In our study, the DPPH and FRAP assays proved that the Si foliar spray treatment increased the antioxidant activity of the flowering Chinese cabbage. The treatment also

increased phenolic content (at N-70). Gunes et al. [49] also observed that the Si treatment significantly increased the non-enzymatic antioxidant activity of sunflower cultivars exposed to drought stress.

The DPPH assay also showed that the Li foliar spray treatment at N-70 improved the antioxidant activity in the flowering Chinese cabbage leaves, as well as the metal-chelating ability of the plant grown hydroponically. Similarly, Bakhat et al. [40] found that all concentrations of lithium applied to spinach increased the activity of antioxidant enzymes. One of the most prominent reasons for activating antioxidant enzymes in plants is the fact that this metallic element might induce reactive oxygen species (ROS) to achieve oxidative stress [50]. Moreover, lithium ions tend to be mostly deposited in the leaves [18,40]. The leaves and flowering stems are valuable parts of flowering Chinese cabbage due to their beneficial effects on health. Therefore, the foliar Li level should be analysed in further research.

The SA foliar spray treatment increased the TEAC antioxidant activity and phenolic content of the plants in pot cultivation at N-70. Choudhury and Panda [51] found that when rice seeds were soaked in SA before sowing, the activity of antioxidant enzymes (CAT, POX, SOD, and glutathione reductase) was reduced. Other researchers also observed that SA can enhance the efficiency of the plant's antioxidant system because it can bind with enzymes such as CAT, APX, aconitase, and carbonic anhydrase [21,42].

5. Conclusions

Our study aimed to investigate the effect of various foliar treatments (Se, Si, Li, V, and SA) and nitrogen nutrition levels (70 and 90 mg N dm^{-3}) on the quality and quantity of the yield of flowering Chinese cabbage grown in two independent systems—pot cultivation (mixture of mineral soil and peat) and hydroponic (Rockwool). The factors under analysis had a diversified and multidirectional influence on the yield, growth, and quality of the plants. The results varied between the two cultivation systems. The yield of flowering Chinese cabbage grown both in the pot cultivation and hydroponically was significantly influenced by different foliar spray treatments and nitrogen nutrition levels. Generally, the plants grown in the hydroponic system were characterized by higher yields than those grown in the pot. The samples sprayed with Se and Si were characterized by the high content of Chl *a*, Chl *b*, and carotenoids in the pot experiment and high antioxidant activity (FRAP in the pot experiment and TEAC, DPPH, and FRAP in the hydroponic experiment), and were easily discriminated from the other samples in the LDA. Similarly, the SA foliar spray treatment significantly influenced the plants' quality and could be classified properly according to the antioxidant activity, chlorophyll content, carotenoid content, lightness, yellowness, and the N level. In the pot experiment, SA-treated plants showed high radical scavenging activity (the TEAC values at N-70) and contained high levels of N, chlorophylls, and carotenoids. In the hydroponic experiment, the SA-sprayed sample was characterized by low antioxidant activity and low content of chlorophylls and lightness but high yellowness. Finally, the samples subjected to different foliar spray treatments could be classified into appropriate groups based on the parameters under analysis. The obtained results confirmed the research hypothesis.

Supplementary Materials: The following are available online https://www.mdpi.com/article/10.3390/agronomy12030737/s1. Table S1. SD values for plant yielding. Table S2. SD values for content of N, P, K, Ca, Mg, Na in leaves. Table S3. SD values for content of Fe, Mn, Zn, Cu in leaves. Table S4. SD values for color parameters. Table S5. SD values for chlorophylls and carotenoids. Table S6. SD values for phenolic content and the antioxidant activity. Table S7. Standardized canonical discriminant function coefficients calculated from the data of the pot experiment. Table S8. Standardized canonical discriminant function coefficients calculated from the data of the hydroponic experiment.

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