Article

Comparative Analysis of Phytochemical Composition and Antioxidant Properties of *Smilax china* Rhizome from Different Regions

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Abstract: This study aimed to investigate variations in the phytochemical compound contents and antioxidant potential of the ethanol rhizome extracts of *Smilax china* L., belonging to the Liliaceae family, from different parts of Korea, namely Uiwang (Mt. Gamnamugol), Gyeonggi Province (SC1); Geochang, Gyeongnam Province (SC2); Yeongwol, Gangwon Province (SC3); and Chungju, Chungbuk Province (SC4). The phenolic and flavonoid contents, radical scavenging activity, and proximate composition of the ethanol extracts from the rhizome samples were determined. The total polyphenol content (TPC) of the extracts ranged between 13.6 and 67.5 mg tannic acid equivalent/g. TPC analysis showed that TPC was higher in SC2 than in SC3, SC4, or SC1. Among the rhizome samples, the SC3 rhizomes had the highest total flavonoid content (TFC) (5.2 mg quercetin equivalents/g). Additionally, SC2 showed the highest radical scavenging activity against DPPH and ABTS$^+$ radicals. Chemical characterization using UPLC/UV revealed that the extracts contained compounds such as apiin, kaempferol-3-rutinoside, and chlorogenic acid. Specifically, in SC2, chlorogenic acid was the dominant compound, which supported the levels observed in the UPLC/UV and HPLC/ELSD investigations. Dioscin, another phytochemical, was detected in SC2, SC3, and SC4, indicating the diversity of compounds among the rhizome extracts. Variations in the phytochemical content and antioxidant activity were observed in the extracts from the different regions, underlining the role of geographical variation in the functional characteristics of *S. china*. The observed differences could have important implications for the medicinal use of *S. china* extracts in applications such as anti-inflammatory treatments, diabetes management, and potential anticancer therapies. This study underscores the critical need to consider geographical origin when sourcing and utilizing *S. china* for therapeutic purposes, as it may significantly impact its bioactive profile and efficacy.

Keywords: antioxidant activity; HPLC/ELSD; phenolic compounds; *Smilax china* L.; UPLC/UV

1. Introduction

Smilax china L., also otherwise known as Smilacis Rhizoma, belongs to the Liliaceae family and is widely recognized in traditional medicine for treating ailments such as rheumatoid arthritis, gout, bacillary dysentery, syphilis, tumors, and inflammation [1–4]. Flavonoids and steroids have been identified as the major bioactive ingredients of *S. china* [5]. These compounds are crucial for antioxidant activity and physiological functions [6,7]. Plant-derived compounds have gained research interest because they possess multiple physiological and medicinal properties. Previous research was conducted on the extraction and analysis of compounds from the rhizomes of *S. china* [8–10]. Rhizomes of *Smilax* spp. are well-known

sources of steroidal saponins [11]. While steroidal saponins have been extensively studied for their bioactivity and role in steroid hormone production [12], this study particularly emphasizes phenolic compounds due to their significant medicinal properties and diverse bioactivity [13]. Phenolic compounds, including flavonoids and stilbenoids, have been shown to possess unique immunosuppressive activities and are active in the treatment of human immune diseases. This focus on phenolic compounds, alongside exploring the plant's rich chemical diversity beyond steroidal saponins, provides a comprehensive understanding of *S. china*'s therapeutic potential.

The increasing focus on plant-derived compounds stems from their multifaceted medicinal and physiological benefits. Previous studies have highlighted the diverse phytochemical composition of *S. china* rhizomes, with significant variation in compounds like chlorogenic acid, known for its strong antioxidant activity, and dioscin, which may have metabolic benefits [14–25]. These variations are greatly influenced by geographical and environmental factors that affect the phytochemical profile and antioxidant potential of *S. china*. Environmental factors are crucial in controlling plants' production and accumulation of secondary metabolites. Geographical location, climate, soil composition, altitude, and other ecological variables can significantly impact the quantity and quality of bioactive compounds produced by plants [26]. These environmental stressors trigger adaptive responses in plants, often leading to the enhanced synthesis of secondary metabolites as a defense mechanism [27]. Notably, studies on related species, such as *S. glabra* Roxb, have demonstrated that biological and environmental factors can significantly influence phytochemical composition and bioactivity, highlighting the importance of these variables in determining the therapeutic potential of natural products [28].

This study aimed to comprehensively analyze and compare the phytochemical composition and antioxidant properties of *S. china* rhizomes collected from various regions in Korea. By identifying and quantifying key compounds, such as chlorogenic acid and dioscin, and assessing their antioxidant capacities, we aim to elucidate how regional differences affect these medicinal properties. This knowledge is crucial for optimizing the therapeutic use of *S. china* and enhancing its agricultural and genetic cultivation practices. By understanding these variations, we can better support sustainable development in the regions where *S. china* is cultivated, thereby maximizing both the medicinal and economic value of this important plant.

2. Materials and Methods

2.1. Plant Materials

The *S. china* rhizomes were collected from Uiwang (Mt. Gamnamugol), Gyeonggi Province (SC1); Geochang, Gyeongnam Province (SC2); Yeongwol, Gangwon Province (SC3); and Chungju, Chungbuk Province (SC4), Korea, on October 2023 (Figure 1). All samples were authenticated by Dr. Y. Lee, Department of Herbal Crop Research, National Institute of Horticultural and Herbal Science, Korea. Voucher specimens (SC1, No. LEE2023-01; SC2, No. LEE2023-02; SC3, No. LEE2023-03; SC4, No. LEE2023-04) were deposited in the Department of Plant Science and Technology, Chung-Ang University, Korea. After collection, all rhizome samples were air-dried in the shade at approximately 20–25 °C with a relative humidity of 60–65% for 15 days. The drying process was conducted in a well-ventilated area to ensure uniform drying. Following this, the dried rhizomes were then cut to a consistent size with pruning shears, ensuring consistency for subsequent analyses.
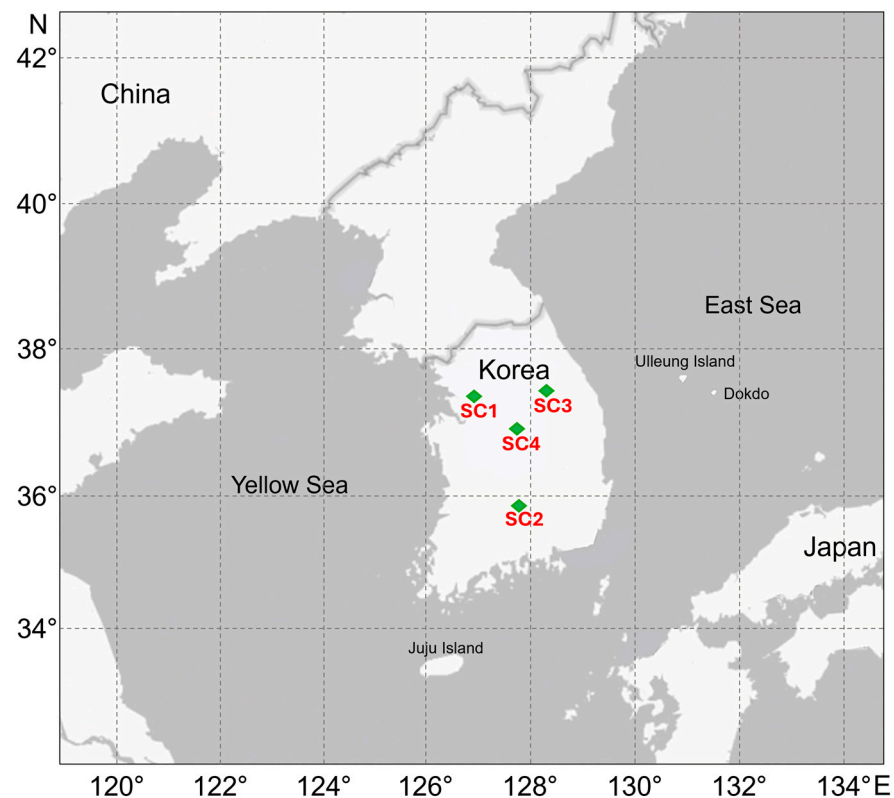
Figure 1. Geographic locations of *S. china* rhizome sample collection sites.

2.2. Instruments and Reagents

Ultra-performance liquid chromatography (UPLC) was performed using a Waters ACQUITY UPLC™ system (Waters Co., Milford, MA, USA), an autosampler, and a tunable ultraviolet (TUV) detector (Waters Co.) with the ZORBAX Eclipse Plus C18 (2.1 × 100 mm, 1.8 μm) (Agilent Co., Santa Clara, CA, USA). Additionally, dioscin analysis was performed using a Waters Alliance e2695 Separations Module (Waters Co.) with a Waters 2424 evaporative light scattering (ELS) detector (Waters Co.). High-performance liquid chromatography (HPLC)-grade solvents, methanol (MeOH), water, and acetonitrile (ACN) were purchased from J. T. Baker (Radnor, PA, USA), and trifluoroacetic acid (TFA) was purchased from Thermo Fisher Scientific (Waltham, MA, USA). The reagents used for the colorimetric method, 2N Folin-Ciocalteu phenol reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH), and 2,2′-azino-bis-3-ethylbenzothiazoline-6-sulphonic acid (ABTS$^+$), were purchased from Sigma-Aldrich (St. Louis, MO, USA). Absorbance was measured using a microplate reader (Epoch, BioTek, Winooski, VT, USA). Standard compounds, such as chlorogenic acid (**1**), apiin (**2**), afzelin (**3**), naringenin (**4**), and dioscin (**5**) (Figure 2), were provided by the Natural Product Institute of Science and Technology (www.nist.re.kr, accessed on 10 July 2023), Anseong, Korea.
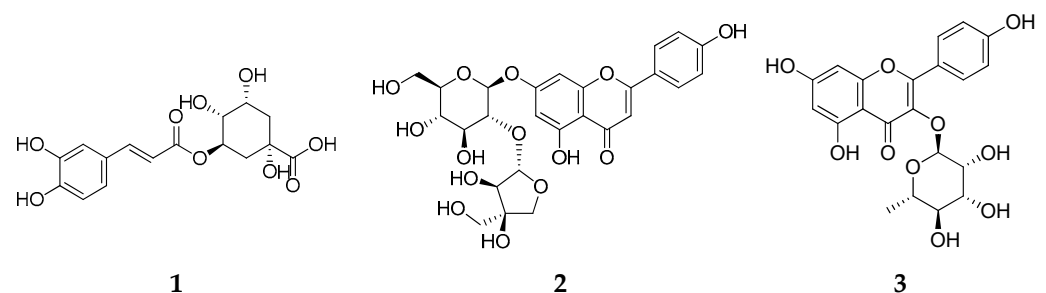

Figure 2. *Cont*.
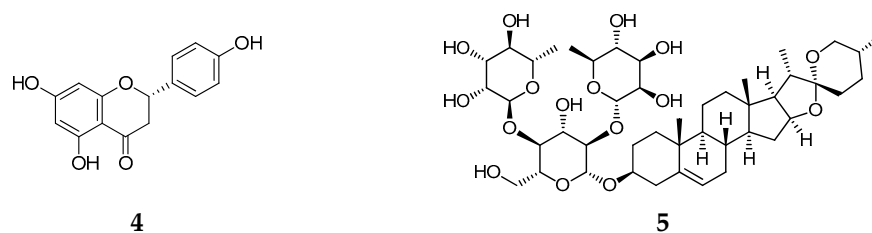
Figure 2. Chemical structures of chlorogenic acid (**1**), apiin (**2**), afzelin (**3**), naringenin (**4**), and dioscin (**5**).

2.3. Sample Extraction

Before extraction, the roots were removed from the rhizome samples were obtained by drying fresh *S. china* rhizomes collected from different regions of Korea. The dried rhizomes were then cut into small pieces and subjected to extraction using absolute ethanol (EtOH) in 30 mg. The samples were extracted in triplicate for 3 h with 300 mL of EtOH using a reflux extractor [29]. Subsequently, the extracts were filtered and concentrated using a rotary vacuum evaporator to obtain concentrated EtOH extracts.

2.4. Preparation of Standards and Sample Solutions

The extracts of all the samples (10 mg) and each standard compound (1 mg) were dissolved in 1 mL of MeOH. Then, they were sonicated for 20 min and filtered using a 0.45 μm polyvinylidene fluoride membrane filter.

2.5. Analysis of TPC

The methodology outlined in a previous study was used to determine the TPC of *S. china* in this study [30]. First, 40 μL of 2 N Folin-Ciocalteu phenol reagent was combined with 60 μL of each extract. Then, the mixture was added to 100 μL of a 7.5% sodium carbonate solution and left in the dark at room temperature for 30 min. At the end of the reaction, the absorbance was measured at 760 nm using a microplate reader (BioTek Co.). Tannic acid was used as a standard to quantify TPC, using a calibration curve as the reference.

2.6. Analysis of TFC

A previously described method was modified was used to evaluate the TFC of the *S. china* samples [31,32]. Briefly, each sample was combined with 100 μL of 2% $AlCl_3$. After incubating the solution for 10 min, absorbance was measured at 430 nm using a microplate reader (BioTek Co.). The TFC was calculated and a calibration curve was constructed using quercetin as the standard.

2.7. DPPH Radical Scavenging Assay

DPPH radical scavenging activity was evaluated as described in previous studies [33,34]. Diluted ascorbic acid was used as the standard solution. Then, 200 μL of the DPPH working solution was added to 10 μL of the standard and test solutions in a 96-well plate. The mixture was incubated at room temperature in the dark for 30 min. Absorbance was measured at 514 nm using a microplate reader (BioTek Co.). The DPPH radical-scavenging rate was calculated using the following equation, and IC_{50} is estimated by plotting DPPH inhibition (%) against extract concentration, fitting a straight line, and using the equation $IC_{50} = (50 - \text{intercept})/\text{slope}$.

DPPH radical scavenging activity (%) = (Blank O.D − Sample O.D)/Blank O.D × 100

2.8. ABTS+ Assay

The ABTS+ assay was used to evaluate the antioxidant activity of *S. china*, following the previously described methodology [35,36]. To measure the absorbance of a 1.0 mg/mL

sample, potassium persulfate and ABTS$^+$ solutions were combined and diluted in distilled water. Ten μL each of the test and standard solutions were placed in a 96-well plate. Then, 200 μL ABTS$^+$ working solution was added. After incubation for 30 min in the dark, the absorbance of the samples was measured at 734 nm using a microplate reader (BioTek Co.). The ABTS$^+$ radical-scavenging rate was calculated using the following equation, and IC$_{50}$ is estimated by plotting ABTS$^+$ inhibition (%) against extract concentration, fitting a straight line, and using the equation IC$_{50}$ = (50 − intercept)/slope.

$$\text{ABTS}^+ \text{ radical scavenging activity (\%)} = (\text{Blank O.D} - \text{Sample O.D})/\text{Blank O.D} \times 100$$

2.9. UPLC/UV Conditions

Using a gradient elution system, the concentrated extracts were quantitatively analyzed using a reverse-phase UPLC system equipped with the ZORBAX Eclipse Plus C18 (2.1 × 100 mm, 1.8 μm). The mobile phase comprised 0.1% TFA in water (A) and ACN (B). The elution conditions were as follows: 5% B for 0–4 min, 5% B for 4 min, 50% B for 27 min, 0% B for 28–30 min, and 5% B for 31–35 min. The column temperature was maintained at 35 °C. Briefly, 3 μL of the sample was injected, the flow rate was maintained at 0.4 mL/min, and the sample was detected at a wavelength of 254 nm.

2.10. HPLC/ELSD Conditions

HPLC analysis was performed using a reverse-phase HPLC system with the YMC Pack-Pro C18 column (4.6 × 250 mm, 5 μm) (YMC Co., Kyoto, Japan). Samples were analyzed using an ELS detector, and the injection volume was 10.0 μL. The column temperature was maintained at 30 °C, and that of the drift tube of the detector was maintained at 85 °C. The flow rate was adjusted to 1.0 mL/min, nitrogen gas was used as the spraying gas at a pressure of 50.0 psi, and the gain was set to five. Separation was performed under gradient elution, and the buffers were 0.1% TFA in water (A) and acetonitrile (B). The elution system conditions were as follows: 0–10 min 7% B; 40 min 70% B; 41 min 100%; 45 min 100% B; 50 min 7% B; 60 min 7% B for 60 min.

2.11. Calibration Curve

Standard stock solutions were serially diluted to obtain five different concentrations and were used to construct a calibration curve. The linearity of the calibration curve was determined based on the correlation coefficient (r^2), and the compound content of the extracted samples was quantified. The calibration function of the two compounds was established based on the peak area (Y), concentration (X, μg/mL), and mean value (*n* = 3) ± standard deviation (SD) (Table 1).

Table 1. Calibration curve equations for chlorogenic acid (**1**), apiin (**2**), afzelin (**3**), naringenin (**4**), and dioscin (**5**).

Compound	t$_R$ [1]	Calibration Equation [2]	Correlation Factor, *r* [2,3]
chlorogenic acid (**1**)	6.9	Y = 5841.3X + 7448.6	0.9999
apiin (**2**)	12.6	Y = 7569.2X + 1310.3	0.9998
afzelin (**3**)	13.8	Y = 15,911X + 7070.6	0.9999
naringenin (**4**)	17.1	Y = 2504X + 2174.9	0.9997
dioscin (**5**)	40.3	Y = 1.6104X + 2.5067	0.9992

[1] t$_R$ = retention time; [2] Y = peak area, X = concentration of the standard (mg/mL); [3] r^2 = correlation coefficient for the five data points in the calibration curve.

2.12. Statistical Analysis

The results were expressed as mean ± SD and were derived from three independent experiments. Statistical analyses were conducted using one-way analysis of variance (ANOVA), followed by Tukey's post-hoc test. All statistical analyses and graphical representations were performed using the GraphPad Prism 8.0.2 statistical software (GraphPad

Software, Boston, MA 02110, USA). NS, *, **, ***, and **** = not significant or significant at $p < 0.05$, 0.01, 0.001, and 0.0001, respectively. Pearson's correlation was conducted and a correlation coefficient network was generated using the MetScape (Version 3.1.3) plugin for Cytoscape [Version 3.10.2; https://cytoscape.org/ (accessed on 5 August 2024)].

3. Results

In this study, the antioxidant activities and TPC, TFC, and chemical compound compositions of *S. china* rhizome extracts were determined.

The TPC values in milligrams of tannic acid equivalent per gram of ext. ranged from 13.6 to 67.5. SC2 had the highest TPC, followed by SC3, SC4, and SC1 (Figure 3). SC3 had the highest TFC (5.2 mg quercetin equivalents/g ext.), followed by SC2, SC4, and SC1. In terms of antioxidant activity, SC2 had the most potent radical scavenging activity against both DPPH ($IC_{50} = 1.7$ mg/mL) and $ABTS^+$ ($IC_{50} = 0.3$ mg/mL), followed by SC4, SC1, and SC3. The chemicals identified in SC1 using UPLC/UV included chlorogenic acid, apiin, afzelin, and naringenin (Table 2 and Figure 4). Pearson's correlation coefficient networking system was also applied to elucidate the relationship between phytochemical compounds and their antioxidant activities (Figure 5). TPC showed a strong positive correlation with chlorogenic acid and a moderate positive correlation with apiin. Conversely, TPC was negatively correlated with DPPH assay, suggesting that higher phenolic content may be associated with reduced DPPH radical scavenging activity. TFC exhibited a strong positive correlation with TPC and a notable positive relationship with DPPH and $ABTS^+$ assays. This indicates that higher flavonoid content correlates with higher antioxidant capacity as measured by these assays. Chlorogenic acid correlated positively with TPC and TFC, as well as with apiin and afzelin, reflecting its significant role in the antioxidant profile of the rhizomes. The data show a negative correlation between DPPH and most other compounds except for $ABTS^+$, where a weak correlation was observed. The relationships between compounds like afzelin, naringenin, and dioscin varied, indicating complex interactions that may depend on the specific antioxidant mechanisms or the bioavailability of these compounds.
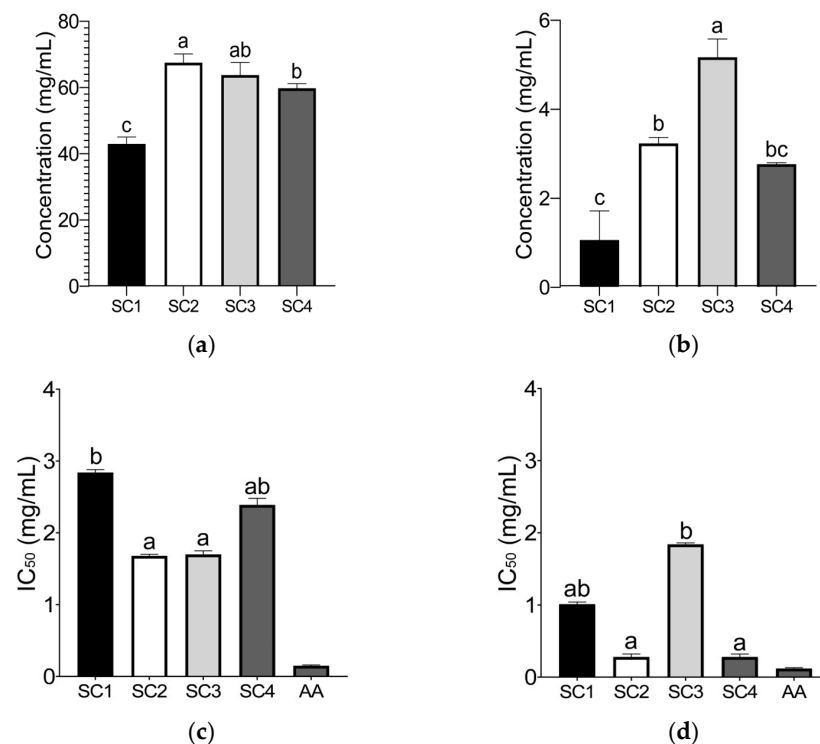

Figure 3. Results of the (**a**) TPC and (**b**) TFC analyses (**c**) DPPH, and (**d**) $ABTS^+$ assays. Each bar presents the mean $\pm$ SD. [a–c] indicates significant differences at $p < 0.0001$. Ascorbic acid (AA) was used as the positive control.

Table 2. Content of standards compounds in ethanol extracts of *S. china*.

Compound	Contents (mg/g) ****			
	SC1	SC2	SC3	SC4
chlorogenic acid (**1**)	1.99 ± 0.03 [c]	13.87 ± 0.52 [a]	7.28 ± 0.13 [b]	6.73 ± 0.01 [b]
apiin (**2**)	0.85 ± 0.02 [d]	2.52 ± 0.07 [c]	2.69 ± 0.07 [b]	4.05 ± 0.03 [a]
afzelin (**3**)	tr	1.56 ± 0.05	ND	ND
naringenin (**4**)	tr	tr	ND	tr
dioscin (**5**)	ND	tr	1.20 ± 0.06 [b]	1.65 ± 0.06 [a]
Total	2.84	17.95	11.17	12.43

ND: not detected; tr: trace; [a–d] different letters indicate significant differences; **** = $p < 0.0001$.

(a)

(b)

(c)

(d)
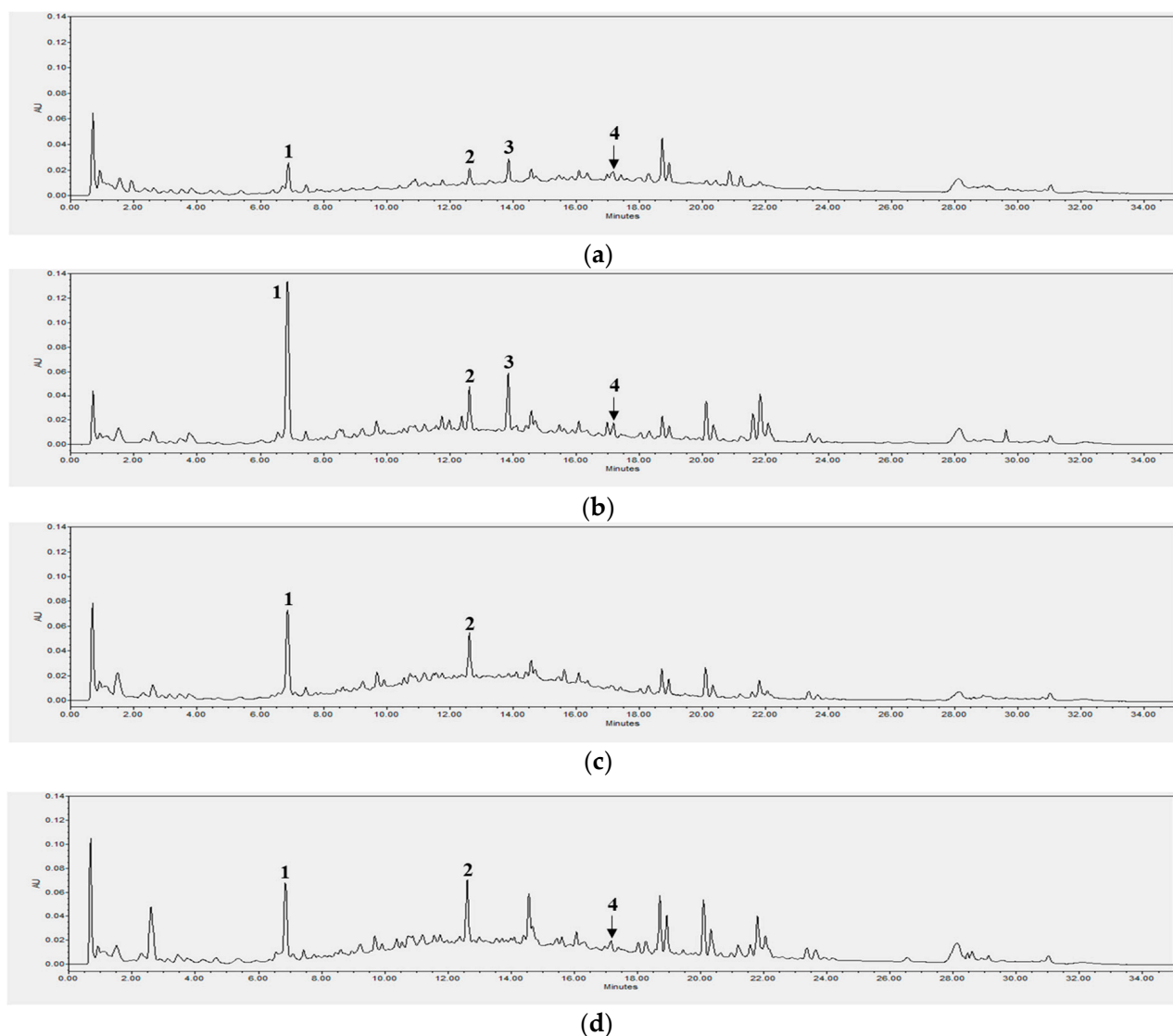
Figure 4. UPLC/UV chromatograms of four *S. china* rhizome samples: (**a**) SC1; (**b**) SC2; (**c**) SC3; (**d**) SC4. (**1**: chlorogenic acid, **2**: apiin, **3**: afzelin, **4**: naringenin).

The predominant chemical compound identified in the rhizome extracts was chlorogenic acid, while kaempferitrin and apiin were the second and third most prevalent chemicals, respectively. These results highlight the variations in phytochemical composition and antioxidant potential among rhizome samples of *S. china* grown in different locations, revealing the influence of geography on the bioactivity of this medicinal plant.
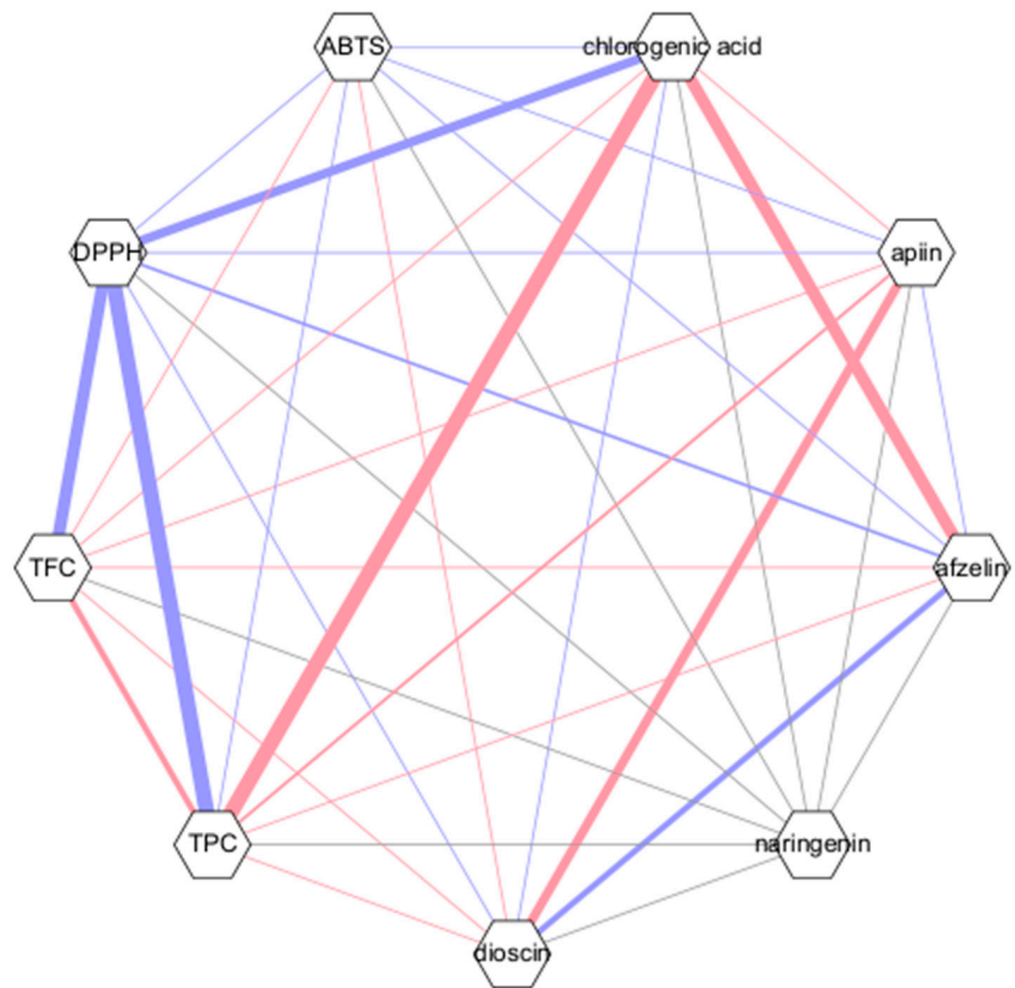
Figure 5. Pearson's correlation coefficient network ($r \geq |1.00|$) among the response variables in phytochemical concentrations and antioxidant activities measures in *S. china* rhizomes. The red and blue lines indicate the positive and negative correlation coefficients between variables, respectively.

This study aimed to analyze the multidimensional qualitative composition and antioxidant properties of extracts from the rhizomes of *S. china* obtained from different locations. The ethanol extracts of the four samples possessed relatively high TPC and TFC values, suggesting that they possessed high phytochemical content. Among the compounds eluted and detected using UPLC/UV, chlorogenic acid was the most abundant, followed by apiin, both of which were present in high concentrations (Table 2 and Figure 4). Naringenin was found in very small quantities, which indicates the variety and total concentrations of the phytochemicals in the rhizome samples (SC1, SC2, SC3, and SC4). Interestingly, SC2 had the highest levels of chlorogenic acid and apiin, indicating that this strain may be a rich source of these bioactive compounds. Further, the HPLC/ELSD results were incorporated into the analysis to determine the dioscin content in the extracts. Notably, SC4 and SC3 contained significant amounts of dioscin at concentrations of 1.65 mg/g ext. and 1.20 mg/g ext., respectively. However, only a small quantity of dioscin was present in SC2. As illustrated in Table 2 and Figure 6, this compound was not identified in SC1 extracts.
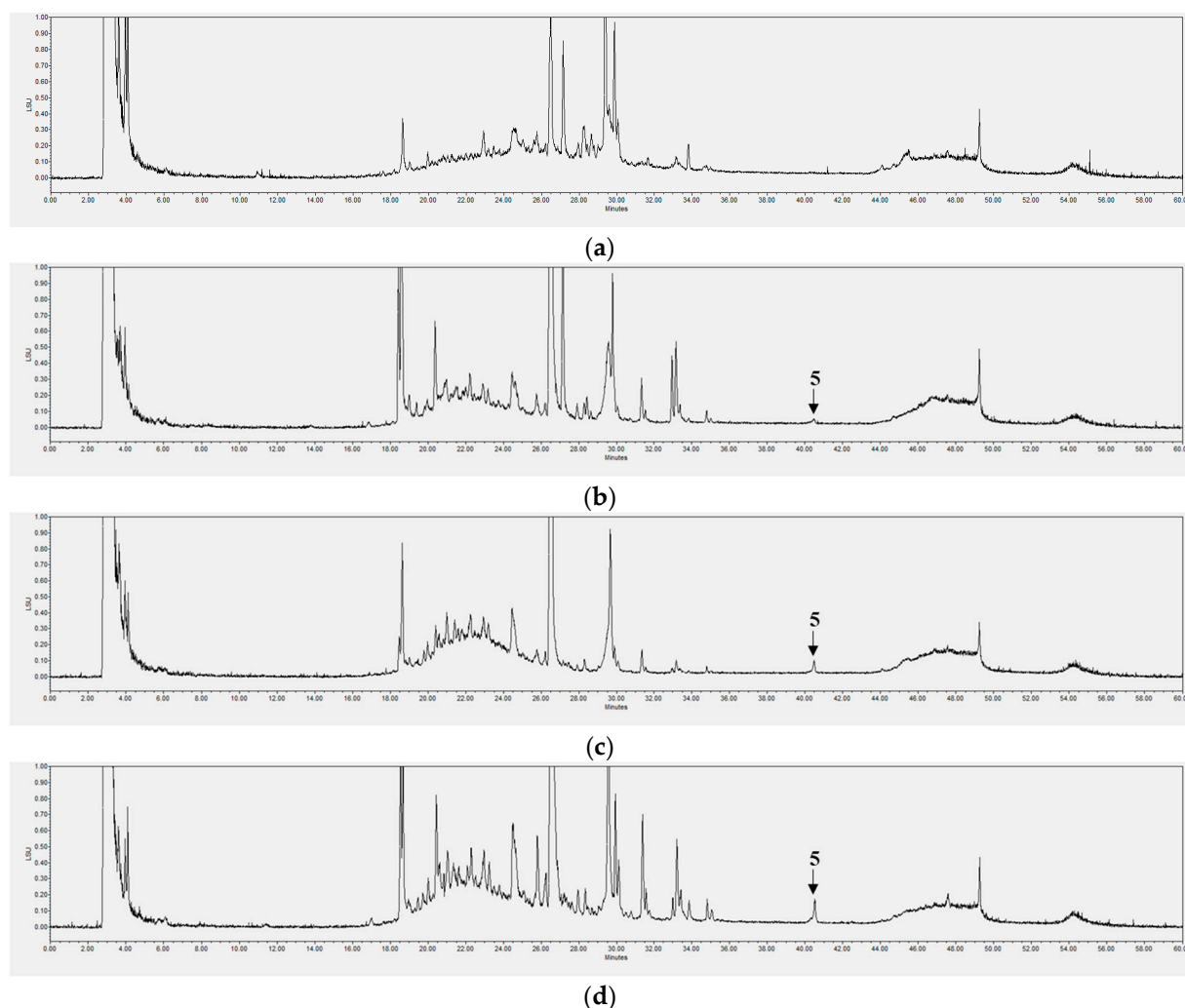
Figure 6. HPLC/ELSD chromatograms of four *S. china* rhizome samples: (**a**) SC1; (**b**) SC2; (**c**) SC3; (**d**) SC4. (**5**: dioscin).

4. Discussion

In this study, UPLC/UV analysis was performed to identify the types of compounds present in the extracts from the rhizomes of *S. china* (Figure 4). The results underscore the richness of the phytochemical profile of the rhizomes from plants grown in different locations, as shown in Table 2. The presence of chlorogenic acid was identified in SC1, which supported the results of earlier UPLC analysis. Furthermore, phytochemical composition analysis of the rhizomes revealed that the main components of SC1 were lepidoside, apiin, and afzelin. In conclusion, phytochemical analysis of rhizome extracts of *S. china* revealed a variety of active compounds and their antioxidant properties (Figure 5). These findings support the usefulness of *S. china* extracts in the management of oxidative stress-associated diseases and highlight the need for further studies on the pharmacological effects of these plant extracts and the underlying molecular pathways. Moreover, these findings highlight that geography plays a role in determining the bioactive properties of this medicinal plant.

In this study, we compared the antioxidant activity, TPC, TFC, and chemical constituents of *S. china* rhizome extracts collected from different locations (Figure 3). The goal of this study was to establish the effects of regional differences on the chemical composition and antioxidant activity of *S. china* extracts. The TPC values varied significantly among the rhizome extracts. Notably, SC2 had the highest TPC, followed by SC3, SC4, and SC1, confirming that there were significant differences in the levels of phenolic compounds in *S. china* extracts from the different regions. These results align with those of other studies

that indicated that environmental conditions, such as soil type and climate, affect the biosynthesis of phenolic compounds in plant tissues (Figure 5) [29,37,38]. The results from the TPC and TFC assays greatly coincide with the DPPH and ABTS$^+$ results. For instance, the TPC and TFC of SC2 were measured to be 67.5 mg TAE/g extract and 3.2 mg QE/g extract respectively. When subjected to DPPH and ABTS$^+$ assays, the IC$_{50}$ values were 1.7 mg/mL and 0.3 mg/mL, respectively. This sample as mentioned above, was the best among its counterparts. These results show that the high antioxidant activity observed can be attributed to the high TPC and TFC of the extracts.

Previous studies also investigated the antioxidant activity of the same plant rhizome. The antioxidant activity of *S. china* rhizomes extracted with hot water and 70% ethanol was investigated in conjunction with the TPC and TFC of the samples [29]. The results showed that using hot water for extraction yields more antioxidant compounds compared to using 70% ethanol as proven by the IC$_{50}$ values from the DPPH (72.9 μg/mL and 42.4 μg/mL) and ABTS$^+$ (81.6 μg/mL and 50.3 μg/mL) assays. Similar to the results of our study, the authors also found a direct relationship between the high TPC and TFC with that of the antioxidant activity. In another study, the methanolic extract of *S. china* was found to harbor antioxidants in the ethyl acetate, butanol, and water fractions with IC$_{50}$ values of 4.6, 8.7, and 9.6 μg/mL, respectively [39]. Authors from both studies reported that their extracts outperformed the positive controls used. In another study, the methanolic extracts of *S. china* from India were also subjected to DPPH assay [37]. The results showed an IC$_{50}$ value of 82 μg/mL, which unlike the previous studies mentioned, showed lower activity compared to the positive control. The present study showed lower activities compared to the aforementioned studies as evident in their IC$_{50}$ values which were reported in μg/mL while the present study used mg/mL. The differences in these results might be attributed to the choice of solvent for extraction. However, the sample source can also be a factor here as different environmental conditions can influence the phytochemical profile of a plant [40].

SC1 is located in a humid continental climate zone, which has hot summers and cold winters. The high-temperature variation among the different seasons and favorable soil conditions for growth may explain the high TPC observed in SC1. Phenolic compounds accumulate in plants under stressful conditions, such as temperature stress [41]. SC2 was found in a humid subtropical climate characterized by mild winters and hot and humid summers. The warm and moist climate of this region is believed to enhance flavonoid biosynthesis, which could explain the high TFC found in SC2. The higher antioxidant activity of SC2 could be attributed to the favorable growth conditions offered by its location, which can enhance the accumulation of bioactive compounds [29]. SC3 was sampled in a mountainous area, which experiences low temperatures and considerably high precipitation throughout the year. These cool and wet conditions could affect the biosynthesis of phytochemicals, resulting in different profiles of bioactive compounds in SC3. These climatic conditions may have contributed to the moderate TPC and TFC in SC3 [14]. SC4 was obtained from an area with a seasonal climate that is characterized by moderate rainfall, therefore the region experiences four well-defined seasons. These environmental conditions may explain the variation in the phytochemical compositions of SC4, including the contents of chlorogenic acid, kaempferitrin, and apiin. These results indicate that the antioxidant activity observed in SC4 may result from the synergistic effects of these compounds [42]. This study provides several practical implications for various industries, particularly the pharmaceutical and food sectors. The diverse phytochemical profiles and significant antioxidant activities identified in *S. china* rhizome extracts suggest their potential use as natural antioxidants in dietary supplements and functional foods.

Moreover, the variation in phytochemical content and antioxidant capacity depending on geographic origin emphasizes the importance of sourcing and quality control in the production of *S. china*-based products. Producers in the food and pharmaceutical industries can leverage these findings by selecting specific regional varieties of *S. china* for targeted therapeutic or nutritional applications, optimizing the bioactive compound content for

desired health benefits. Future research should focus on genetic, environmental, and molecular factors to enhance understanding and utilization of these medicinal plants.

5. Conclusions

The findings of the present study revealed the effects of geographical variation on the phytochemical content and antioxidant potential of *S. china* extracts. The observed differences in TPC, TFC, antioxidant activity, and chemical composition indicate that regional variation should be considered when exploring the full therapeutic value of this medicinal plant. More studies should be conducted to identify the environmental factors, such as soil composition, climate, and altitude, as well as genetic factors responsible for such regional variations and determine the conditions that promote the biosynthesis of desirable plant compounds. This understanding is crucial, as pharmaceutical companies can develop optimized *S. china* extracts specific to each region for use in antioxidant supplements or functional foods. Therefore, further research on the pharmacological effects and clinical use of *S. china* extracts is required to maximize their therapeutic applications in managing oxidative stress-related diseases and other ailments. The findings of this study are valuable for enhancing our knowledge of the medicinal properties of this plant and the development of natural antioxidant remedies.

Author Contributions: HPLC analysis, C.-D.L.; antioxidant activity assay, C.-D.L. and N.P.U.; experimental design and conception, Y.L. and D.-H.L.; supervision, writing, and editing, S.L. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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