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Comprehensive Analysis of Phenolic Compounds, Carotenoids, and Antioxidant Activities in *Lactuca sativa* var. *longifolia* Cultivated in a Smart Farm System

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Abstract: Smart farming is a promising strategy for future agriculture, and the global market for smart agriculture is growing rapidly. The aim of this study was to compare the quality of agricultural products based on their cultivation method. The components and antioxidant activities of *Lactuca sativa* (LS) var. *longifolia* cultivated using conventional agriculture methods (CAMs) and smart farm agriculture methods (SAMs) were compared. $ABTS^+$ and DPPH radical scavenging activity assays were performed to compare the antioxidant activities of LS grown using CAMs and SAMs. High-performance liquid chromatography with a reverse-phase column was employed to analyze the phenolic and carotenoid compounds. In both the SAM and the CAM, β-carotene was found to be the most abundant compound. LS grown using the CAM had high total polyphenol content and $ABTS^+$ radical scavenging activity, while LS grown using the SAM had high individual phenolic content and DPPH radical scavenging activity. This study developed a new method of SAM and confirmed that SAM produces a higher quantity of phenolic compounds and total flavonoid contents than CAM in LS. This study also highlights the SAM's functioning, gives crop quality inspection guidelines, and standardizes LS. The new SAM is effective for application in undeveloped urban spaces, is more convenient than the CAM, and represents a way to develop and manage LS quality.

Keywords: HPLC; *Lactuca sativa*; phenolic compound; carotenoid; smart farm; antioxidant activity

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1. Introduction

Agriculture has seen a diverse array of methods developed globally, each meticulously tailored to local climates and soil compositions [1]. These innovative agricultural practices have undeniably played a pivotal role in sustaining a plentiful global food supply. This achievement hinges on the meticulous optimization of three fundamental facets of crop production: the manipulation of the surrounding environment, the utilization of advanced agricultural techniques, and the selection of suitable crop varieties. In this context, the emergence of smart farming agriculture methods (SAMs) has recently garnered substantial attention for their remarkable ability to exert precise control over the farming environment through advanced agricultural technology [2–4].

Crucial determinants of the agricultural environment encompass an intricate web of factors, including soil quality, atmospheric conditions, water resources, soil temperature, light intensity, air composition, relative humidity, soil and water alkalinity, and the availability of essential nutrients indispensable for robust plant growth [5]. The challenge lies in the delicate balance and intricate interplay among these factors, each of which significantly

impacts crop quality and yield [6]. Traditionally, managing this complex interplay has often been a difficult undertaking. However, recent breakthroughs in smart agriculture, often referred to as smart farming, have harnessed the potential of Internet of Things (IoT) systems. These IoT systems incorporate small electronic devices equipped with an array of sensors, enabling real-time monitoring of the farming environment and facilitating responsive actions to optimize crop growth [7,8]. The application of IoT technology in crop agriculture has ushered in a new era of precision agriculture, offering refined control over essential resources such as nutrients and water, while simultaneously enhancing data collection pertaining to the cultivation environment [9].

Furthermore, the confluence of technological advancements and agricultural innovation has given rise to an array of hydroponic agricultural techniques [10,11]. These encompass deep flow techniques [12], nutrient film systems [13,14], aeroponics, capillary cultures, deep water cultures [15,16], and the ebb and flow system (EBB) [17]. These hydroponic methods represent a departure from traditional soil-based agriculture, utilizing alternative growth substrates and precise nutrient delivery to further optimize crop development.

Lactuca sativa (LS) var. *longifolia*, a member of the Asteraceae family, finds extensive use as a salad vegetable and is cherished in traditional Chinese medicine. With a lifecycle spanning one to two years, LS typically reaches a height of 1 m. Its stems are characterized by their straight, shiny, smooth, and hairless attributes, though they may tend to crack. While native to Europe, LS is cultivated in smart farms globally, with a flowering period typically occurring from June to July. Of particular interest, LS is known to contain lactucin, a flavonoid glycoside recognized for its potential sleep-inducing properties [18]. Furthermore, LS exhibits variations in its phenolic compound composition, influenced by factors such as harvest time, climate, cultivation methods (including temperature and fertilization), and storage conditions [19].

Motivated by the fascinating interplay between advanced agricultural methods and plant phytochemistry, the primary objective of this study is to discover whether significant differences exist in the total polyphenol content, total flavonoid content, and antioxidant capacity of LS when cultivated employing the SAM versus the conventional agriculture method (CAM). Additionally, an in-depth comparative analysis will be conducted to discern variations in the contents of eight representative LS compounds, shedding light on potential implications for both nutritional value and the broader agricultural landscape.

2. Materials and Methods

2.1. Plant Materials

The experimental cohort comprised LS plants cultivated utilizing both the SAM and the CAM under the auspices of Plantcia Co., Ltd., Daejeon, Republic of Korea.

2.2. Preparation of SAM and CAM

LS plants subjected to the SAM were cultivated hydroponically using an intermittent ebb and flow (EBB) system within a horizontal agriculture framework. The process commenced with the sowing of LS seeds on a black urethane sponge, initiating a growth period of 14 days (Figure 1A). The EBB hydroponics system, a flood and drain approach, orchestrates nutrient delivery to the plants at specific intervals. The system functions by inundating the growing area with a nutrient solution, which subsequently drains back into a reservoir containing a timer-controlled pump. This hydroponic technique proves particularly advantageous for crops that benefit from alternating dry-to-wet cycles. Notably, the EBB system offers versatility through its adjustable operating time for the submersible pump, a feature with implications for the motor's lifespan. It is imperative to highlight that, per the manufacturer's recommendations, continuous 24-h operation of the motor is discouraged due to the associated shortened lifespan—typically less than two weeks. The performance and durability of the pump motor hold paramount importance in the commercialization prospects of the SAM, significantly impacting maintenance costs. Key

components of the EBB system encompass the nutrient reservoir, the plant or flood tray, the submersible water pump, and the timer. Depending on specific requirements, a perforated or net pot containing hydroponic growth media may also be employed to cradle the plant within the flood tray. This system's operation is facilitated as the growth medium absorbs the nutrient solution, subsequently supplying the plant roots. In this study, the ambient conditions in the agricultural chamber were meticulously regulated, maintaining an average temperature of 24 °C and a relative humidity level of 55%. To meet the photosynthetic needs of the LS plants, an artificial light source comprising full-spectrum LEDs (Samsung (Ridgefield Park, NJ, USA) LM301HONE, LM301H-CRI80 2:1) was employed. Light intensity was recorded at 7286 lux, with a light flux density (Ppfd) of 133 μmol/m^2/s at a distance of 30 cm. Illumination followed a daily light irradiation cycle of 12 h. As for the nutrient solution, its composition adhered to precise parameters: a total dissolved solids concentration of 1250 ppm (ppm 500 scale), a potassium chloride concentration of 1820 ppm (700 scale), an electrical conductivity of 2500 μs/cm, and a pH level of 4.5.

(**A**) (**B**)

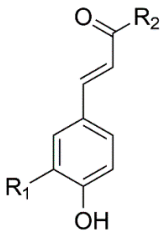
Figure 1. LS grown in SAM (**A**) and CAM (**B**).

The CAM LS samples in this study were cultivated in Daejeon, South Korea, using horticultural topsoil sourced from Shinsung Minerals Co. in Goesan, South Korea. The topsoil composition consisted of 51.5% cocopeat, 15% perlite, 13% vermiculite, 10% peat moss, 10% zeolite, 0.4% fertilizer, and 0.1% humic acid, with a bulk density of less than 0.3 mg/m^3. Furthermore, the topsoil exhibited a pH range of 5.0 to 7.0 in a 1:5 (w/w) ratio, and the electrical conductivity was measured at less than 1.2 dS/m (Figure 1B). The cultivation period spanned approximately two months, from April to June, and the same LS variety as that grown in the smart farm served as the seedling source. Dried LS samples were pulverized and used for extraction.

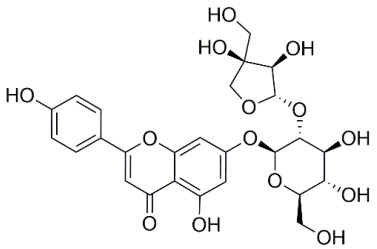
Each sample (10 g) was extracted three times with EtOH (80 °C, 200 mL × 3 h) and concentrated in vacuo (50 °C).

2.3. Instruments and Reagents

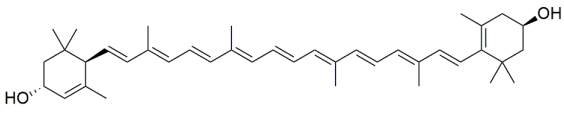
High-performance liquid chromatography (HPLC) analyses were conducted employing Agilent (Santa Clara, CA, USA) 1260 Infinity II Quaternary pumps, an autosampler, and a diode array detector (DAD) WR (Dionex, Sunnyvale, CA, USA). HPLC-grade solvents, including chloroform ($CHCl_3$), ethyl acetate, water, and methanol (MeOH), were purchased from J. T. Baker (Phillipsburg, PA, USA) and were of the highest purity for precise analytical procedures. Extraction solvents, namely $CHCl_3$ and MeOH, were sourced from the same reputable supplier, ensuring consistent quality throughout the analyses. DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) solutions were purchased from Sigma (St. Louis, MO, USA); potassium persulfate was purchased from Junsei (Tokyo, Japan). A dedicated Epoch microplate spectrophotometer manufactured by BioTek (Winooski, VT, USA) was employed for microplate reader analyses, guaranteeing accuracy and reproducibility. Reagents for the analysis included 2N Folin–Ciocalteu reagent, sodium carbonate, and aluminum (III) chloride hexahydrate, all obtained from Sigma (Burlington, MA, USA) and selected for their recognized purity and reliability. Standard materials used in the study, such as ascorbic acid, β-carotene, and lutein, were acquired from the Natural Product Institute of Science and Technology (www.nist.re.kr) in Anseong, Korea (Figure 2), ensuring the use of authenticated and high-quality reference compounds in the analytical process.



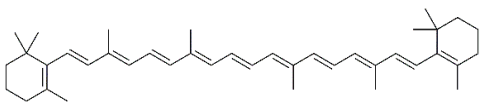
Compound	R_1	R_2
Chlorogenic acid (**1**)	OH	quinic acid
Caffeic acid (**2**)	OH	OH
Chicoric acid (**3**)	OH	caftaric acid
Ferulic acid (**4**)	OCH_3	OH
Rosmarinic acid (**6**)	OH	3,4-dihydroxyphenyllactic acid



Apiin (**5**)



Lutein (**7**)



β-Carotene (**8**)

Figure 2. Chemical structures of compounds **1**–**8**.

2.4. $ABTS^+$ Antioxidant Activity

The analysis of LS extracts from both the SAM and the CAM followed the procedure outlined by Heo et al. [20]. In brief, a solution of $ABTS^+$ and potassium persulfate was prepared and diluted with distilled water to achieve an absorption of 1.3 ± 0.04 mg/mL. After a 24 h incubation period in a darkroom, each sample extract was introduced to the $ABTS^+$ radical stock solution. The remaining radical concentration was subsequently quantified at 734 nm after a 30 min incubation period using a microplate reader (Epoch, BioTek, Winooski, VT, USA). As a positive control, ascorbic acid was utilized within a concentration range of 0.0125 to 0.5 mg/mL. The $ABTS^+$ scavenging activity (IC_{50}) was expressed as the concentration required to reduce the absorbance of the control by 50% using the solvent alone. All experimental procedures were carried out at room temperature.

2.5. DPPH Antioxidant Activity

The assessment of LS extracts from both the SAM and the CAM followed the methodology outlined by Choi et al. [21]. Briefly, a 2 mM DPPH solution was prepared by dilution in ethanol to achieve an absorption rate of 1.2 ± 0.04 mg/mL. Subsequently, 200 µL of the DPPH reagent and 10 µL of each extract were combined in a tube, vortexed, and allowed to react in darkness for 30 min. The remaining radical concentration was quantified at 514 nm after 30 min using a microplate reader. Ascorbic acid served as a positive control, with concentrations ranging from 0.0125 to 0.5 mg/mL. The DPPH scavenging activity (IC_{50}) was determined as the concentration required to reduce the absorbance of the control by 50% using the solvent alone. All experimental procedures are carried out at room temperature.

2.6. Analysis of the Total Polyphenol and Total Flavonoid Content

Total polyphenols and flavonoids in LS extracts from the SAM and the CAM were quantified according to established methods with some modifications [22,23]. For total polyphenol analysis, 60 µL of 2N Folin–Ciocalteu phenol reagent (Sigma-Aldrich, St. Louis, MO, USA) was added to 60 µL of the extract, and the mixture was allowed to react with 60 µL of 15% Na_2CO_3 (Daejung Chemicals, Siheung, Republic of Korea) for 30 min. Total flavonoids were measured by adding 100 µL of 2% $AlCl_3$ to 100 µL of the extract and incubating the mixture for 10 min. Absorption measurements for total polyphenols and flavonoids were conducted at 760 nm and 430 nm, respectively, using microplate readers. Gallic acid and quercetin were employed as standard materials to generate the respective calibration curves. All experimental procedures are carried out at room temperature.

2.7. Sample Preparation and HPLC Analysis for Phenolic Compounds

Five grams each of the LS extracts from the SAM and the CAM were used for HPLC analysis. For the quantitative evaluation of the LS extracts, they were dissolved in MeOH and filtered through 0.45 µm PVDF membrane filters. Each sample was dissolved in MeOH at a concentration of 50 mg/mL. Chlorogenic acid, caffeic acid, chicoric acid, apiin, rosmarinic acid, and ferulic acid were dissolved in 1 mL of MeOH and filtered through a 0.45 µm PVDF membrane filter. Analysis was conducted using reverse-phase HPLC with a YMC-Pack Pro C18 column (25 cm × 4.6 mm, 5 µm). The injection volume was 10 µL, and a DAD was used. The temperature of the column was maintained at 25 °C, and the flow rate was set at 1 $mL \cdot min^{-1}$. The detector wavelength was set at 280 nm. The analysis was conducted with a gradient elution system using a mobile phase composed of 0.5% acetic acid in water (A) and acetonitrile (B). The gradient elution program was as follows: 0 min 95% A, 10 min 70% A, 25 min 70% A, 30 min 20% A, 35 min 100% B, 40 min 100% B, 50 min 95% A, and 55 min 95% A.

2.8. Sample Preparation and HPLC Analysis for Carotenoids

One hundred milliliters of $CHCl_3$:MeOH (1:1) was added to 10 g of the samples obtained by drying LS grown using the SAM and the CAM, and the mixture was extracted

under ultrasonic extraction at room temperature for 30 min. The extracts were filtered with a 0.45 µm PTFE membrane filter. Specimens were stored in sealed bottles and stored in refrigerators with light protection until they were used for analysis. Quantitative analysis was performed using a reverse-phase HPLC with a YMC carotenoid (C30) column (25 cm × 4.6 mm, 3 µm). The injection volume was 10 µL, and a DAD was used. The detector wavelength was set at 454 nm. The column temperature was maintained at 25 °C. The flow rate for 1 min was set to 1 mL. The mobile-phase solution consisted of water:MeOH (25:75) (A) and ethyl acetate (B). The gradient elution program was as follows: 0 min 83% A, 10 min 70% A, 25 min 70% A, 30 min 20% A, 35 min 100% B, 40 min 100% B, 50 min 83% A, 55 min 83% A.

2.9. Calibration Curves

The standard stock solutions used in phenol analysis and carotenoid analysis were dissolved in MeOH and $CHCl_3$:MeOH (1:1), respectively, and filtered through 0.45 µM PVDF and PTFE membrane filters, respectively. The working solution used to create the calibration curve was prepared by diluting the standard stock solution to the desired concentrations. The content of the analyte was measured on the corresponding calibration curve. The standard calibration function was calculated using the peak area (Y) and concentration (X, mg/mL), with the mean ± standard deviation (n = 5) presented.

2.10. Statistical Analysis

All results were reported as the mean ± standard deviation (SD). Statistical significance ($p < 0.05$) was determined via analysis of variance (ANOVA) followed by Duncan's multiple range test in Minitab 16 software (Minitab Inc., State College, PA, USA).

3. Results and Discussion

The cultivation of crops is a complex endeavor that can be influenced by various factors, including climatic variations and susceptibility to diseases [24]. To overcome these challenges and achieve higher yields of top-quality crops with reduced land usage, researchers have been developing a range of smart farming technologies. In this study, we investigate the phytochemical content of LS grown in two distinct environments: SAM and CAM. Figure 3 presents a comparative analysis of the total polyphenol and flavonoid content in LS extracts from the SAM and the CAM. Remarkably, the extraction yield for CAM and SAM exhibited minimal differences, with values of 17.01% and 17.90%, respectively. This parity in extraction yield implies that both cultivation methods can yield comparable quantities of phytochemicals from LS. Polyphenols constitute a class of aromatic compounds abundant in plants, characterized by two or more phenolic hydroxyl groups and an affinity for binding to proteins and other compounds [25]. These compounds have garnered attention due to their myriad of reported benefits, including antioxidative, anticancer, anti-inflammatory, and visual enhancement properties [26]. Interestingly, our findings reveal that the total flavonoid content in LS cultivated using the SAM and the CAM did not exhibit a significant difference, measuring 38.7 and 39.1 mg QE/g, respectively. However, a notable disparity arose in the total polyphenol content, with values of 46.5 mg GAE/g for the SAM and 60.9 mg GAE/g for the CAM. This observation aligns with prior research, such as Cho et al.'s study [27], which found that shiitake mushrooms grown using the CAM contained higher total polyphenol content than those from the SAM. Similarly, Lakhiar et al. demonstrated that LS treated with various aeroponic atomizers exhibited elevated total polyphenol content and enhanced antioxidant activity compared to untreated LS [28]. The divergence in experimental results likely stems from differences in cultivation practices, lettuce varieties, drying techniques, extraction solvents, and methodologies employed.

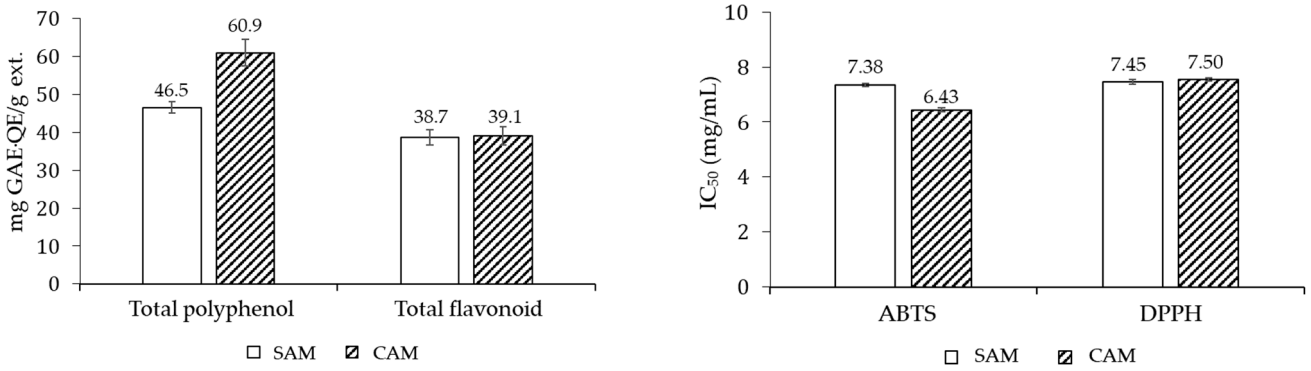


Figure 3. Comparison of total polyphenols and total flavonoids (**A**) and antioxidant ability (**B**) in LS grown using SAM and CAM.

Further examination of LS extracts led us to analyze six of the most prevalent phenolic compounds found in LS: chlorogenic acid, caffeic acid, chicoric acid, apiin, rosmarinic acid, and ferulic acid [29–34]. Additionally, the two carotenoids β-carotene and lutein were quantitatively assessed [35]. The results of the present study unveiled that ferulic acid and rosmarinic acid were particularly abundant among phenolic compounds in SAM-grown lettuce. Specifically, the ferulic acid content in LS extracts from the SAM and the CAM measured 2.91 mg/g and 0.66 mg/g, respectively, while the rosmarinic acid content was recorded at 0.16 mg/g for SAM and 0.04 mg/g for CAM. Additionally, the β-carotene content was lower in SAM-grown lettuce, with values of 4.50 mg/g compared to 5.92 mg/g in CAM-grown lettuce. Similarly, lutein content was more pronounced in CAM-grown lettuce, registering at 1.44 mg/g compared to 1.00 mg/g in SAM-grown lettuce. These findings suggest that SAM cultivation may be more effective in promoting the synthesis of diverse phenolic compounds. In summary, the comparative analysis of the phytochemical content performed in lettuce cultivated using the SAM and the CAM has provided valuable insights into the potential advantages of smart farming. While the extraction yields were comparable, SAM cultivation demonstrated its superiority in producing various phenolic compounds, including ferulic acid, rosmarinic acid, and chlorogenic acid. These results underscore the potential of smart farming to enhance the nutritional quality of crops, which holds promise for sustainable agriculture in the face of evolving agricultural challenges.

In addition to assessing the extraction yield and phytochemical content of LS cultivated in the SAM and the CAM, in vitro assays were conducted to evaluate the antioxidant activity of LS extracts. These assays, employing $ABTS^+$ and DPPH radicals, provide crucial insights into the potential health benefits of LS grown under different agricultural methods (Figure 3).

Both SAM-grown and CAM-grown LS displayed substantial antioxidant activity. Interestingly, SAM-grown LS exhibited superior performance in the DPPH assay, with an IC_{50} of 7.45 mg/mL, highlighting its proficiency in scavenging hydrophobic substances [36]. On the other hand, CAM-grown LS demonstrated a stronger antioxidant capacity in the $ABTS^+$ assay, with an IC_{50} of 6.43 mg/mL, signifying its effectiveness in combating both hydrophilic and hydrophobic radicals [37]. This divergence in antioxidant activity is attributed to the differential accumulation of phytochemicals, specifically phenolic compounds and carotenoids, in LS cultivated using the SAM and the CAM, respectively.

Phenolic compounds, a group of phytochemicals with well-documented antioxidant properties, are known for their ability to directly eliminate hydroxyl radicals (OH-) [38,39]. Notably, caffeic and chlorogenic acids, prominent among phenolic compounds, have been recognized as potential anti-inflammatory agents and have even found applications in the development of novel diabetes drugs aimed at enhancing insulin sensitivity and secretion [40]. Additionally, rosmarinic acid has demonstrated its prowess in reducing

reactive oxygen species, thereby mitigating oxidative stress, and exhibits antibacterial, immunomodulatory, and antifungal activities [41]. Furthermore, carotenoid compounds such as β-carotene and lutein serve as precursors of vitamin A, contribute to the scavenging of active oxygen species, and possess anticancer properties [42]. Given the presence of numerous phenolic compounds and carotenoids in LS, it is evident that LS offers protection against various diseases and plays a pivotal role in enhancing immunity.

To provide a quantitative assessment of specific phytochemicals, including chlorogenic acid, caffeic acid, chicoric acid, apiin, rosmarinic acid, ferulic acid, β-carotene, and lutein, a reverse-phase HPLC coupled with a gradient elution system was utilized (Figure 4). This approach allowed for effective separation and detection of these compounds using a DAD (Figures 4 and 5).

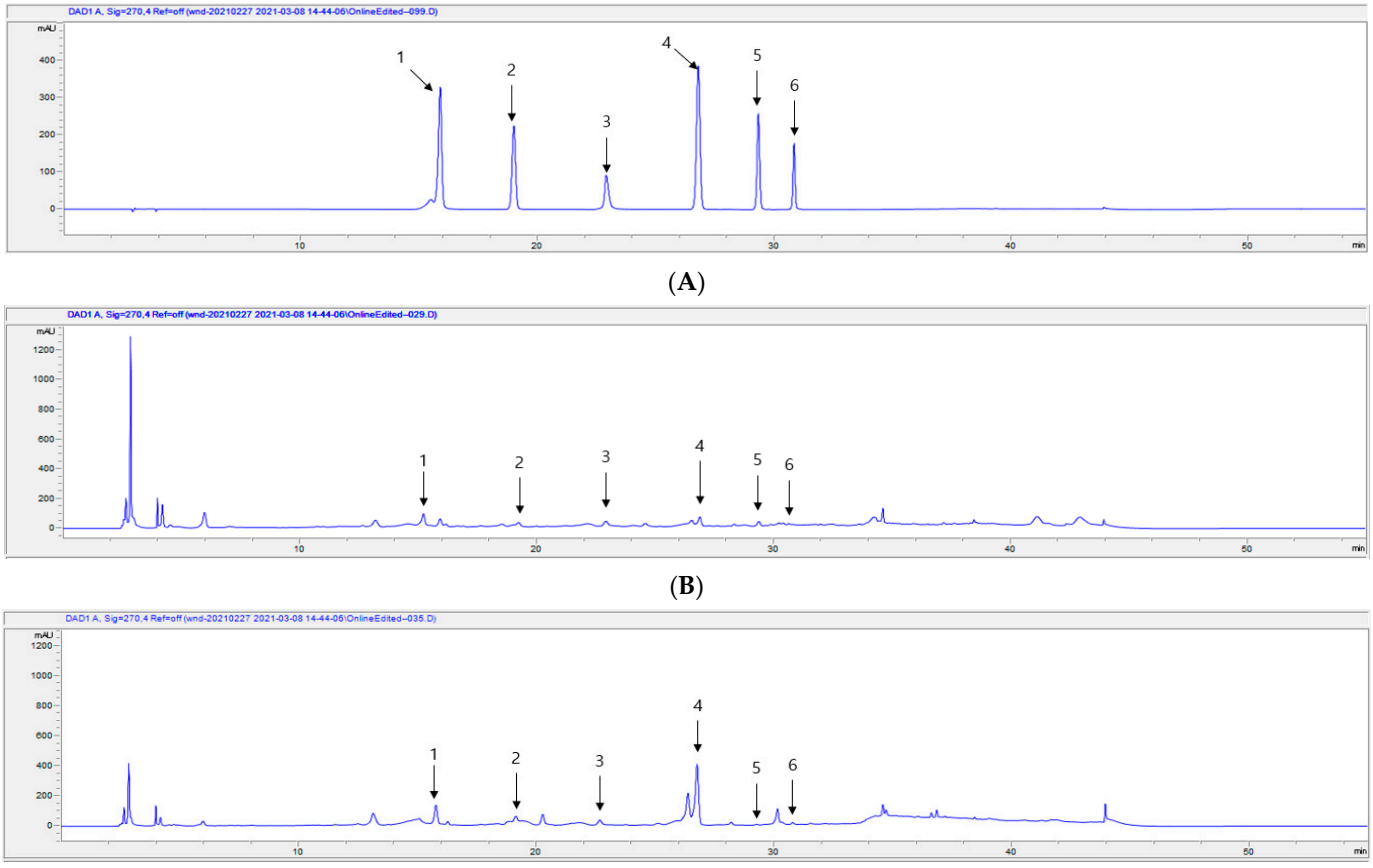


Figure 4. HPLC chromatograms of phenolic compounds [chlorogenic acid (**1**), caffeic acid (**2**), chicoric acid (**3**), ferulic acid (**4**), apiin (**5**), and rosmarinic acid (**6**)] (**A**), SAM (**B**), and CAM (**C**).

For phenolic compounds, including chlorogenic acid, caffeic acid, chicoric acid, apiin, rosmarinic acid, and ferulic acid, UV detection at a wavelength of 280 nm was optimized due to their UV-absorbing properties. Carotenoids, namely β-carotene and lutein, also absorb UV light but were quantified at a wavelength of 454 nm to prevent interference from other substances. Calibration curves, generated by plotting peak area against prepared concentrations, demonstrated high correlation coefficients (r^2) ranging from 0.9996 to 1.0000 (Table 1). The resulting data revealed that SAM-grown LS contained a total phenolic content of 4.12 mg/g, whereas CAM-grown LS registered a slightly lower content of 2.31 mg/g (Table 2). Conversely, CAM-grown LS excelled in the production of carotenoid compounds, with a total carotenoid content of 7.36 mg/g, compared to 5.50 mg/g in SAM-grown LS (Table 2). It is worth noting that among the phenolic compounds, ferulic acid exhibited a notably higher concentration in SAM-grown LS compared to CAM-grown LS.

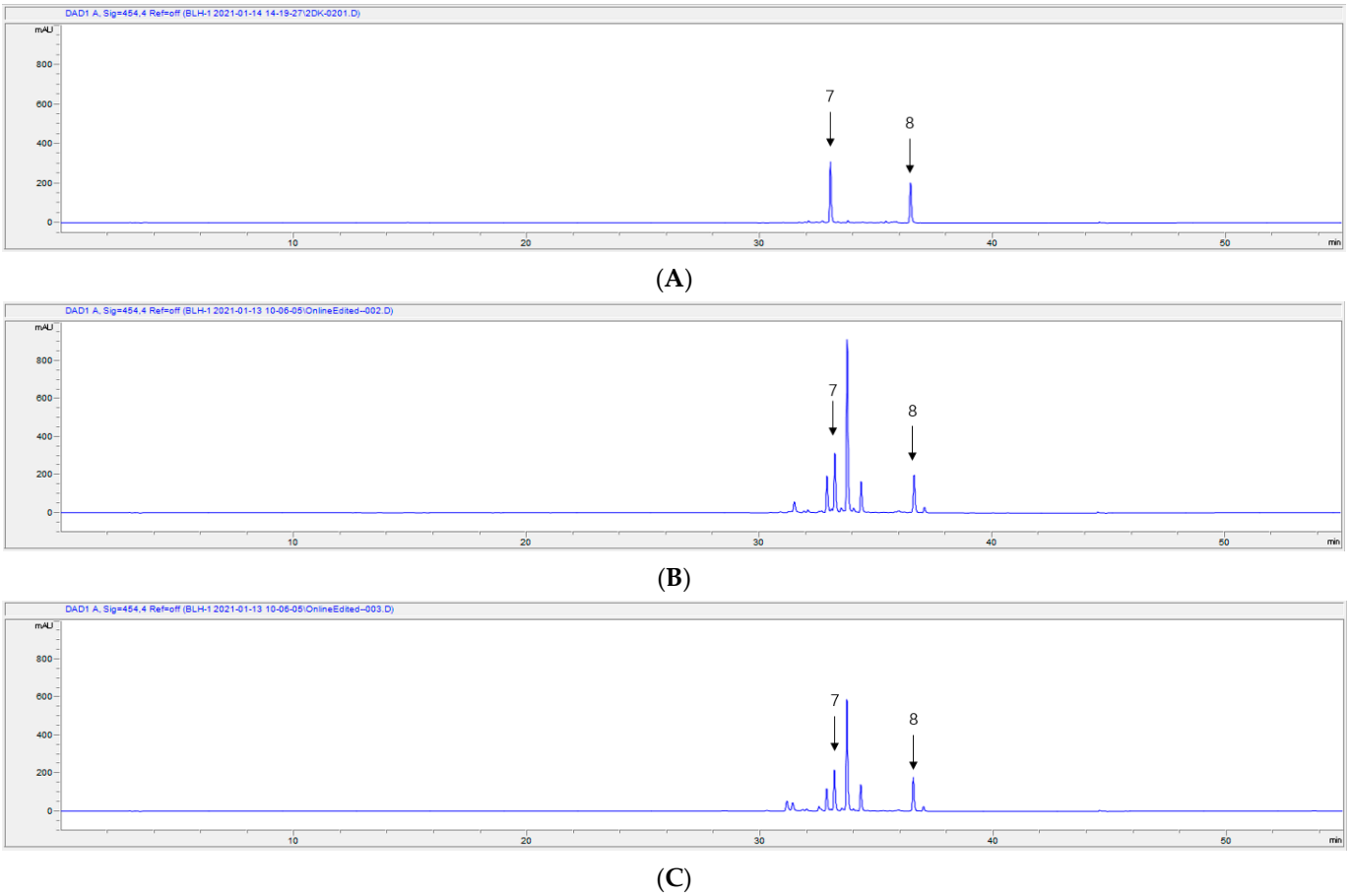


Figure 5. HPLC chromatograms of carotenoids [lutein (**7**) and β-carotene (**8**)] (**A**), SAM (**B**), and CAM (**C**).

Table 1. Calibration curves of phenolic compounds and carotenoids.

Compound	t_R	Calibration Equation [a]	Correlation Factor, r^2 [b]
Chlorogenic acid (**1**)	15.9	Y = 6.2014X − 6.4179	0.9998
Caffeic acid (**2**)	19.1	Y = 17.413X + 89.05	0.9998
Chicoric acid (**3**)	23.0	Y = 9.0481X + 52.711	0.9997
Ferulic acid (**4**)	26.7	Y = 16.742X − 46.292	0.9999
Apiin (**5**)	29.0	Y = 15.508X + 79.194	0.9998
Rosmarinic acid (**6**)	30.8	Y = 8.87X − 4.2388	1.0000
Lutein (**7**)	33.2	Y = 11.022X − 117.7	0.9996
β-Carotene (**8**)	36.7	Y = 2.1054X − 9.6781	0.9999

t_R = retention time. [a] Y = peak area, X = concentration of standards (μg/mL). [b] r^2 = correlation coefficient based on five data points in the calibration curves (0.5–0.001 mg/mL).

These findings not only affirm the distinctive phytochemical profiles of LS cultivated using different methods but also underscore the influence of the growth environment on the synthesis of these compounds. The observations in the present study align with existing literature, such as Park et al.'s investigation [43], which emphasized the impact of light conditions on carotenoid content. Additionally, the concept that plants produce metabolites in response to environmental stressors [44] resonates with the present study, affirming that SAM cultivation favors the production of phenolic compounds while potentially limiting carotenoid production. In conclusion, the comprehensive analysis of the antioxidant capacity and phytochemical composition of LS from the SAM and the CAM conducted in this study has revealed intriguing insights. While both cultivation methods yielded LS with robust antioxidant activity, SAM-grown LS displayed superior DPPH scavenging

abilities, while CAM-grown LS excelled in $ABTS^+$ radical scavenging. The differences in phytochemical composition, specifically the higher phenolic content in SAM-grown LS and increased carotenoids in CAM-grown LS, underscore the potential of smart farming to tailor the phytochemical profile of crops to meet specific nutritional and health-related objectives. These findings have important implications for advancing sustainable and health-conscious agricultural practices in the face of evolving agricultural challenges.

Table 2. Contents of phenolic compounds and carotenoids in SAM and CAM.

Compound	Content (mg/g Extract)	
	SAM	CAM
Chlorogenic acid (**1**)	0.34 ± 0.15^{a}	0.31 ± 0.02^{a}
Caffeic acid (**2**)	0.20 ± 0.10^{b}	0.41 ± 0.01^{a}
Chicoric acid (**3**)	0.51 ± 0.23^{b}	0.63 ± 0.01^{a}
Ferulic acid (**4**)	2.91 ± 0.26^{a}	0.66 ± 0.04^{b}
Apiin (**5**)	trace	0.25 ± 0.01
Rosmarinic acid (**6**)	0.16 ± 0.01^{a}	0.04 ± 0.00^{b}
Lutein (**7**)	1.00 ± 0.00^{b}	1.44 ± 0.00^{a}
β-Carotene (**8**)	4.50 ± 0.02^{b}	5.92 ± 0.02^{a}

The values represent the mean ± SD. Different letters within the same compound indicate significant differences ($p < 0.05$), as determined by Duncan's multiple range test.

4. Conclusions

In the course of this study, the efficacy of a novel SAM was introduced and assessed. It was also compared with a CAM regarding the cultivation of LS. This investigation has provided valuable insights into the potential advantages of employing smart farming techniques, particularly SAMs, in crop production. The findings reveal that SAM cultivation results in a higher accumulation of phenolic compounds while demonstrating a reduced yield of carotenoid compounds compared to CAM cultivation. This intriguing divergence in phytochemical composition underscores the potential of the SAM as an effective and versatile method for crop growth. The elevated phenolic content suggests that the SAM has the capability to enhance the nutritive value and health-promoting properties of LS. Furthermore, this study emphasizes the practical functionality of the SAM and offers guidelines for assessing crop quality using this innovative approach. In pursuit of standardization in the cultivation of LS, this research contributes to the broader effort of improving crop quality through controlled and technology-driven agricultural practices. Importantly, the results of the present study provide compelling evidence of the capacity of LS components, including phenolic acids and carotenoids, to effectively mitigate the damage caused by free radicals. While the exact mechanisms underlying these results require further research, this study lays a solid foundation for understanding the potential health benefits associated with consuming crops grown in smart farm environments. In conclusion, the introduction of the new SAM represents a promising avenue for agriculture, particularly in maximizing crop yields and enhancing the quality of produce. Its adaptability for use in redundant urban spaces, coupled with the convenience it offers over traditional open-field methods, positions the SAM as a viable solution for addressing the growing demand for sustainable and nutritious crops. By providing compelling evidence of the health-promoting properties of LS grown in SAMs, this research underscores the importance of further investigations into smart farming technologies. These technologies not only hold the potential to revolutionize agriculture but also to contribute significantly to addressing global food security and dietary health challenges in an increasingly complex and dynamic world.

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