Eleutherococcus senticosus extracts through a supercritical CO2 extraction process for antioxidant application

Zening Wang
China Tobacco Henan Industrial Limited Company
Gaolei Xi
China Tobacco Henan Industrial Limited Company
Changtong Lu
China Tobacco Henan Industrial Limited Company
Yibo Ning
China Tobacco Henan Industrial Limited Company
Xueying Cao
China Tobacco Henan Industrial Limited Company
Zhifei Chen
China Tobacco Henan Industrial Limited Company
Yongzhen Zhao
China Tobacco Henan Industrial Limited Company
Shuqing Ao
Northeast Forestry University
Tao Jia
Northeast Forestry University
Xiuhua Zhao
xiuhuazhao@nefu.edu.cn

Northeast Forestry University

Research Article

Keywords: Supercritical CO2, Eleutherococcus senticosus, Extract, Response surface methodology, Antioxidant activities

Posted Date: February 2nd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8677453/v1

Additional Declarations: No competing interests reported.

Abstract

Purpose

This study aimed to optimize the supercritical CO_2 (SC-CO_2) extraction process for *Eleutherococcus senticosus* extracts (ESE) to maximize yield, and to evaluate the antioxidant activity of the obtained extracts.

Methods

The extraction was performed using SC-CO_2 under conditions below the boiling point to preserve heat-sensitive compounds. Key factors (temperature, pressure, and time) were investigated, and the optimal process conditions were determined using the response surface methodology. The antioxidant activity of ESE was assessed by measuring its scavenging effect on 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radicals.

Results

The optimal extraction conditions were identified as a temperature of 60°C, pressure of 30 MPa, and an extraction time of 2 hours, yielding 1.88 ± 0.05% of ESE. Phytol was identified as a primary constituent. The ESE exhibited notable antioxidant activity, and its concentration exhibited a positive correlation with antioxidant activity.

Conclusion

This study made a significant contribution to the field by enhancing the extraction process of plant extracts and providing a valuable direction for the study of antioxidant bioactive substances.

1. Introduction

Eleutherococcus senticosus, which belongs to the Araliaceae family, is a shrub that can reach altitudes of between 1–6 meters. It is found in forests or shrublands, at elevations ranging from hundreds of meters to 2000 meters above sea level (Wang et al. 2018; Zhang et al. 2023). The plant thrives in warm and humid climates and exhibits tolerance to cold temperatures and partial shade. *Eleutherococcus senticosus* is a medicinal and edible plant which is clinically used for the recovery and treatment of cardiovascular and central diseases, which on human health has been paid more and more attention (Mu et al. 2022). They are the important material basis of pharmacological activities such as anti-oxidation, anti-inflammatory, cell protection, anti-hyperglycemia, anti-hyperlipidemia, and anti-cancer (Chen et al. 2022; Jia et al. 2023; Li et al. 2021).

Plant extracts are complex mixtures of bioactive compounds, synthesized by plants, present in leaves, stems, buds, seeds, fruits, glands and flowers (Khwaza et al. 2025; Verdeguer et al. 2020; Chen et al. 2023). Extracts are odorous phytochemicals, i.e. secondary metabolic products, derived from plants. Since time immemorial, these substances have been employed in folk and alternative medicine to alleviate pain and a variety of maladies, as well as serving as insecticides and repellents (Gómez-L et al. 2025; Ma et al. 2025; Mangalagiri et al. 2021). The use of these substances in cosmetics and perfumery is primarily due to their highly pleasant aromatic properties. In the food industry, extracts are similarly valued for their functional properties as flavoring agents and preservatives, effectively inhibiting oxidation, microbial contamination, and the proliferation of pathogenic bacteria responsible for foodborne illnesses. (Sana et al. 2021; Shen et al. 2024).

As the use of the plant extracts grows, the study of extraction techniques has become increasingly important due to their significant impact oils on the extracts yield and composition (Uwineza et al. 2020). Despite their widespread use, traditional methods such as hydrodistillation and solvent extraction are associated with significant limitations, including prolonged extraction times, high energy consumption, and reduced extraction (Guo et al. 2022). It is evident that the utilisation of these methodologies frequently culminates in a diminished extraction yield and an augmented restriction in the range of extracted components (Wang et al. 2022). Inefficient use of *Eleutherococcus senticosus* biomass may result in material loss (Dimitrijević et al. 2024). Therefore, developing effective extraction techniques is crucial for advancing the extracts sector. The employment of supercritical CO_2 (SC-CO_2) for

extraction purposes offers a novel solution that has the potential to enhance the yield of the extract to a considerable degree. This method offers several advantages, including high selectivity, low operating temperatures, and a simpler extraction process.

Carbon dioxide (CO_2) is the most extensively utilised solvent in supercritical fluid technology, employed for the extraction of compounds with high biological value due to its relatively low cost, toxicity, and safety status (Bocevska et al. 2007; Cui et al. 2024; Dashtian et al. 2024; Haloui et al. 2017; Khalati et al. 2023). The supercritical CO_2 system typically comprises a sample chamber linked to a high-pressure vessel, a heating and cooling system, and pumps or compressors. The operational mode of the device under consideration enables the control of pressure, temperature, and SC-CO_2 flow. As asserted by Guo et al. (Guo et al. 2022) and Zhang et al. (Zhang et al. 2022) the purification of the compounds extracted by this solvent does not necessitate the use of a cosolvent. This is due to the fact that the solvation properties of the solvent can be simply adjusted by altering the conditions (pressure, temperature). From a sustainability perspective, the use of CO_2 in industrial processes renders it a highly attractive alternative to organic solvents, as it contributes to reducing the carbon footprint and global greenhouse gas emissions, thereby mitigating the environmental impact of these processes. (Uribe et al. 2011). The SC-CO_2 extraction process does not oxidize the target extract, making it particularly suitable for extracting active components from natural medicines. The technology's numerous advantages include safety, high efficiency, and the potential for recyclability, which have prompted extensive research and application of this technology in various fields.

In this work, the extracts were extracted from the dried leaves of *Eleutherococcus senticosus* using a SC-CO_2 extraction method. This technique allowed the extraction to occur at a temperature significantly below the boiling point, effectively preventing the oxidation and loss of heat-sensitive components. The extraction process was optimized through single-factor tests and response surface methodology. The components of the extracts were analysed by gas chromatography-mass spectrometry (GC-MS), and the antioxidant activity of the extracted *Eleutherococcus senticosus* extracts (ESE) against 2,2-diphenyl-1-picrylhydrazyl free radicals was evaluated. This method has been shown to significantly improve the extract yield, while offering distinct advantages in terms of operational simplicity, environmental sustainability, and high efficiency. This study thereby establishes a solid foundation for further research on the antioxidant properties of ESE.

2. Experimental

2.1 Raw material

Eleutherococcus senticosus was obtained from Changbai Mountain. *Eleutherococcus senticosus*, belonging to the Araliaceae family. Its project identifier is GBIF ID: 4645. They are crushed with a grinder, sieved (40 mesh), and then stored in a sealed plastic bag in a cool and dry place before use. All the blades used in the experiment were from the same batch, ensuring the accuracy of the experiment.

2.2 Methods

The *Eleutherococcus senticosus* leaves were inspected to remove impurities, insect eggs, and moldy leaves, followed by grinding into a fine powder. Put the *Eleutherococcus senticosus* powder into the material tank, adjust the parameters of the supercritical machine, with the supercritical machine parameters being: extraction pressure of 25 to 35 MPa; extraction temperature of 40 to 70 ^{o}C. Introduce CO_2 gas and start the extraction process. The extraction time condition is 1 to 2 h. Measure the content of the extracted substance and calculate the yield of the extract. Each experiment is repeated 3 times, and the results are taken as the average.

2.3 Experimental section

Through the preliminary experiment, the main factors affecting the extraction of *Eleutherococcus senticosus* extracts (ESE) by Supercritical CO_2 (SC-CO_2) are: extraction pressure (25 MPa, 30 MPa, 35 MPa), extraction temperature (40 ^{o}C, 45 ^{o}C, 50 ^{o}C, 55 ^{o}C, 60 ^{o}C, 65 ^{o}C, 70 ^{o}C) and extraction time (1 h, 2 h, 3 h). The single factor experiment list of SC-CO_2 is shown in Table 1. The yield of the extract is calculated using Eq. (1):

Table 1
Summary of single factor optimization experiments using Supercritical CO_2 extraction.

No.	Extraction temperature (°C)	Extraction pressure (MPa)	Extraction time (h)
1	50	25	2
2	70	25	2
3	60	25	1
4	60	30	2
5	60	35	3
6	50	30	1
7	70	30	3
8	60	30	2
9	60	30	2
10	70	35	2
11	60	25	3
12	60	35	1
13	50	35	2
14	60	30	2
15	60	30	2
16	50	30	3
17	70	30	1

$$Y = \frac{m_1}{m_2} \# (1)$$

Where Y is the yield of the extract, %; m_1 is the quality of the extract extracted by the SC-CO_2 method, kg; m_2 is the quality of the raw material, kg.

2.4 Optimization of enzymatic extraction conditions by Box-Behnken design

The Box-Behnken design (BBD) was utilised to optimise the effects of three key factors: extraction temperature (X_1: 50 °C, 60 °C, 70 °C), extraction pressure (X_2: 25 MPa, 30 MPa, 35 MPa), and extraction time (X_3: 1 h, 2 h, 3 h). This approach was employed to enable a more comprehensive investigation of the interactions among these variables. The relationship between the interaction of three factors and extract yield was examined under three coded levels (− 1, 0, 1), as presented in Table 2. Furthermore, the BDD method was employed to enhance the yield of the extracts, and its precise expression is delineated in Eq. (2).

Table 2
Design of FCCCD experiment and analysis of result.

Run	BBD experiments				ANOVA							
					Source	Sum of squares	DOF	Mean Square	F	P		
	X_1	X_2	X_3	Y								
1	50	25	2	1.55	Model	0.2227	9	0.0247	85.52	< 0.0001**		
2	70	25	2	1.56	X_1	0.0036	1	0.0036	12.49	0.0095		
3	50	35	2	1.51	X_2	0.0001	1	0.0001	0.3889	0.5527		
4	70	35	2	1.61	X_3	0.0392	1	0.0392	135.51	< 0.0001		
5	50	30	1	1.62	X_1X_2	0.0020	1	0.0020	7.00	0.0331		
6	70	30	1	1.59	X_1X_3	0.0036	1	0.0036	12.44	0.0096		
7	50	30	3	1.72	X_2X_3	0.0016	1	0.0016	5.53	0.0510		
8	70	30	3	1.81	X_1^2	0.041	1	0.041	141.93	< 0.0001		
9	60	25	1	1.55	X_2^2	0.1129	1	0.1129	390.28	< 0.0001		
10	60	35	1	1.57	X_3^2	0.0055	1	0.0055	19.13	0.0033		
11	60	25	3	1.71	Residual	0.0020	7	0.0003				
12	60	35	3	1.65	Lack of Fit	0.0014	3	0.0005	3.17	0.1473		
13	60	30	2	1.83	Pure Error	0.0006	4	0.0002				
14	60	30	2	1.8	Cor. total	0.2247	16					
15	60	30	2	1.82	Credibility analysis of the regression equations							
16	60	30	2	1.83	Index mark	SD	Mean	CV (%)	Press	R^2	R_{Adjust}^2	$R_{Predicted}^2$	AP
17	60	30	2	1.82	*Y*	0.0170	1.68	1.01	0.0237	0.9910	0.9794	0.8944	23.7642
* p < 0.05, significant; * * p < 0.01, highly significant; * ** p < 0.001, extremely significant.												
a. The results were obtained with Design Expert 8.0 software.												
b. X1 is the enzyme concentration (%), X2 is enzymatic hydrolysis temperature (°C), X3 is pH, and Y is yield of the extracts (%)												

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j \# (2)$$

Where *Y* is the predicted response value, β_0, β_i, β_{ii} and β_{ij} represents the regression coefficients of linear, square, intercept, and interaction processes, respectively. X_1, X_2, and X_3 are independent variables.

2.5 Study on surface characteristics of *Eleutherococcus senticosus*

To observe the microstructure of the powder, the microstructure of the powder after SC-CO_2 extraction at different extraction pressures was observed by Scanning Electron Microscope (SEM). After the powder was ground to a uniform particle size, the sample was mounted on a metal sample stage using double-sided conductive tape, followed by gold sputter coating to enhance its electrical conductivity. The sample was then subjected to testing and analysis using the scanning electron microscope.

2.6 Analysis of the extract composition

The water in the extracts of *Eleutherococcus senticosus* was removed using anhydrous Na_2SO_4. Next, 20 μL of the extract was dissolved in 2 mL of n-hexane and then filtered through a 0.45 μm membrane to prepare the samples needed for gas chromatography-mass spectrometry (GC-MS) measurement. Thermo Scientific ISQ 7610 J&W TG-5MS gas chromatography column (30 m × 0.25 mm × 0.25 μm) with an injection volume of 1.0 μL and an injection port temperature set at 230 ^{o}C. The heating program commenced at 90 ^{o}C for 1 min, followed by a temperature increase of 5 ^{o}C/min to 150 ^{o}C, which was maintained for 1 min. This was succeeded by another ramp of 5 ^{o}C/min to 180 ^{o}C, held for 2 min, and subsequently increased at a rate of 5 ^{o}C/min to 230 ^{o}C, where it was held for 3 min. The carrier gas used was nitrogen with a flow rate of 1.0 mL/min, and the shunt ratio was set to 50:1. The mass spectrometry conditions were as follows: an EI^+ ion source with the ionization source temperature at 230 ^{o}C. The electronic energy was maintained at 70 eV, with a filament flow rate of 0.2 mA. The interface temperature was set at 250 ^{o}C, and the mass scanning range extended from 20 to 500 amu. The chemical composition of the extract was determined by NIST17 mass spectrometry.

2.7 *Eleutherococcus senticosus* extract through hydrodistillation method

Precisely 50 g of the dried leaf powder from *Eleutherococcus senticosus* were carefully placed into a 3000 mL round-bottom flask. After adding 750 mL H_2O, the mixture was heated for 3 h using a 100 V heating jacket. Following this process, the extract samples underwent analysis according to Method 2.6, ensuring accurate and reliable results.

2.8 Free radical scavenging activity assay

The initial step involves the preparation of a 4 mg/mL 2,2-diphenyl-1-picrylhydrazyl solution, which is to be achieved by employing absolute ethanol. The subsequent stage of the process is to create a 100 mg/mL ESE solution in absolute ethanol, followed by a half dilution to achieve eight distinct concentration levels, ranging from 100 to 0.39 mg/mL. Proceed by taking 100 μL of the DPPH solution and combining it with 100 μL of the ESE solutions at different concentrations. Following a 30-minute period of light avoidance reaction, the measurement of the extinction coefficient at a wavelength of 517 nm is required. To ensure reliability, the experiment was conducted in triplicate, and the scavenging capacity was calculated accordingly. For comparative analysis, use ascorbic acid as a positive control group (Lu et al. 2018). The scavenging rate of DPPH free radicals is calculated according to the following formula Eq. (3):

$$R = \frac{A_0 - A_1}{A_0} \times 100\% \# (3)$$

Among them, A_0: absorbance value of 100 μL of DPPH solution and 100 μL of absolute ethanol; A_1: Absorbance value of a mixture of 100 μL of DPPH solution and 100 μL of sample solution.

The preparation of a 100 mg/mL ESE solution in ethanol and perform a half dilution to achieve eight distinct concentration levels, ranging from 100 to 0.39 mg/mL. Then, add 50 μL of 6 mmol/L $FeSO_4$ solution, 50 μL of H_2O_2, and 50 μL of salicylic acid solution to each concentration of ESE. Allow the reaction to proceed at 37°C for 30 min. The experiments were performed in parallel, with each measurement repeated three times to ensure accurate determination of the radical scavenging rate. Ascorbic acid was used as the positive control. The radical scavenging rate was calculated according to Eq. (3). In this study, two values are of particular significance: A_0, which is defined as the extinction coefficient of 100 μL of hydroxyl radical solution and 100 μL of absolute ethanol, and A_1, which is defined as the extinction coefficient of a mixture of 100 μL of hydroxyl radical solution and 100 μL of sample solution (Liu et al. 2021).

3. Results and discussion

3.1 Optimization of conditions affecting the extracts yield

The bioactive compounds sequestered within the cell walls are transported by the supercritical CO_2 fluid. Since most target constituents are intracellularly localized, disruption of the cell walls is essential to facilitate efficient extraction. Firstly, a single-factor experiment was conducted, with the aim of identifying the variable that has the greatest impact during the extraction

process. Within the determined range, three variables (extraction temperature, extraction pressure, and extraction time) were initially selected for analysis. In accordance with the prevailing individual conditions, a series of extractions were conducted on the subject. As demonstrated in Fig. 1, the yield of extracts exhibits a gradual increase when the extraction pressure is ranged from 25 to 30 MPa. This phenomenon can be attributed to the fact that increasing the extraction pressure enhances the diffusion rate of CO_2. This, in turn, leads to several significant effects: first, it enhances the interaction between the solvent and the pore structure; second, it increases solvent solubility; and third, it accelerates the dissolution rate of the extracts. In the temperature range of 40–60 ^{o}C, the yield of the extracts significantly increases with rising temperature, indicating that the viscosity of CO_2 has a considerable impact on the extract extraction at lower temperatures. The reduction in viscosity enhances the yield of the extracts. When the appropriate temperature range is broken, the heat-sensitive substances in the the extracts are oxidized, destroying the cell activity. The extraction time also affects the extraction efficiency of the extracts. As extraction time increases from 1.0 to 1.5 hours, the extract yield gradually rises; beyond this point, the yield approaches saturation over time.

3.2 Optimizing parameters by response surface methodology

The Box-Behnken design (BBD) model within the response surface methodology (RSM) was employed to analyze the interactive effects of different factors on the yield of *Eleutherococcus senticosus* extracts (ESE). The three influencing factors include: X_1: extraction temperature (X_1: 50 ^{o}C, 60 ^{o}C, 70 ^{o}C); X_2: extraction pressure (X_2: 25 MPa, 30 MPa, 35 MPa); and X_3: extraction time (X_3: 1 h, 2 h, 3 h). The BBD test method was used to process the data. The results of the tests and the results of the RSM are presented in Table 2. The predicted ESE value was 1.77%, While the actual measured ESE yield was 1.82%. The prediction equation of ESE yield is shown in Eq. (4):

$$Y_{\text{extract}} = 1.82 + 0.0213X_1 - 0.0037X_2 + 0.0700X_3 + 0.0225X_1X_2 + 0.0300X_1X_3 - 0.0200X_2X_3 - 0.0988X_1^2 - 0.1638X_2^2 - 0.0363X_3^2 \# (4)$$

As can be seen from Table 2, it can be seen that ESE has a determination coefficient (R^2) of 0.99, indicating that the model has extremely high explanatory power and predictive accuracy, and the actual response is very consistent with the predicted response. It can be seen from Table 2 that F and P values are 85.52 and less than 0.0001 for the ESE model, indicating that the model has good adequacy, high precision and reliability. In the analysis of variance for ESE yield, factors X_1, X_3, X_1X_2, X_1X_3, X_1^2, X_2^2 and X_3^2 were significant ($P < 0.05$), and factors X_2 and X_2X_3 ($P > 0.05$). Therefore, the adjusted coefficient of determination (adjusted $R^2 = 0.9794$) indicates a strong correlation between the experimental data and the predicted values. The low coefficient of variation of ESE yield was 1.01, indicating the high repeatability and reliability of all experiments.

As illustrated in Fig. 2, the 3D interaction profile is accompanied by three diagnostic plots. To verify the reliability and relevance of the model predictions, it is necessary to check the actual probability Fig. 3a, normal probability Fig. 3b, and external residuals Fig. 3c. Figure 2a shows the interaction of factors X_1 and X_2 on ESE yield, while factor X_3 remains at an intermediate level. As the temperature of the extraction process is increased, the efficiency of the extraction process is increased and eventually decreased. Figure 2b shows the interaction between factors X_3 and X_1, which significantly increases the ESE yield. In Fig. 2c, the production of ESE is influenced by two factors, X_2 and X_3, and its ESE production remains high after reaching a certain level.

To enhance model reliability and minimize the influence of extraneous factors, a systematic analysis was conducted to examine the relationship between predicted and actual values. The reliability of the experiment is very high, while other factors produced during the experiment have relatively little influence on the experimental results. The constructed model not only matches the experimental data, but can also be intuitively reflected in Fig. 3a. As illustrated in Fig. 3b, the majority of data points are closely clustered around the diagonal line, indicating that the normalized residuals are normally distributed. This figure also presents the results for internal residuals and normal probability plots. The internal study residuals of each group of experiments are also in the ± 3 range Fig. 3c, indicating that the experimental data on the fluctuation amplitude of internal factors is limited and the influence of experimental internal factors is not significant, further proving that the BBD model has satisfactory fitting performance.

Design Expert 13.0 software was used to verify the experiment. The maximum yield of the extracts was determined to be 1.88% under the optimized extraction conditions: temperature of 69.52°C, pressure of 25.22 MPa, and time of 2.99 h. When the extraction temperature was set at 60°C and the pressure at 30 MPa, the optimal extraction time was found to be 2 h, resulting in a yield of 1.88 ± 0.05%. This result is close to the predicted value.

3.3 Study on surface characteristics of *Eleutherococcus senticosus* powder

The microstructure of *Eleutherococcus senticosus* powder was examined using scanning electron microscopy (SEM), allowing for an analysis of the effects of the extracts on the microstructure before and after extraction. As illustrated in Fig. 4a displays a powder made from *Eleutherococcus senticosus* leaves, which has a relatively flat surface with a few particles. This phenomenon can be attributed to the pulverisation of the desiccated leaves of *Eleutherococcus senticosus*, a process that has been shown to result in the disruption of cellular structures and the subsequent formation of particulate matter. Figure 4b is the supercritical CO_2 extraction (SC-CO_2) on the *Eleutherococcus senticosus* leaf powder. In this case, the cellular structure of *Eleutherococcus senticosus* is significantly damaged, with disrupted cell walls and altered overall cell morphology. The findings suggest that, under conditions of elevated pressure, the cells undergo rupture and the integrity of their cell walls is compromised. This alteration enhances the contact between intracellular contents and the external environment, thereby increasing extract yield.

3.4 Compound identification of the *Eleutherococcus senticosus* extracts

Hierarchical cluster analysis was utilized to generate a heat map illustrating the composition of the extracts, as depicted in Fig. 5. The x-axis is divided into two sections: the water vapour phase and the supercritical carbon dioxide phase, representing distinct extraction techniques. The y-axis categorizes the extract components according to their relative abundance. The analysis revealed significant compositional differences between the extracts obtained using these two methods. The hydrodistillation method was found to yield extracts primarily composed of (1R,7S,E)-7-isopropyl-4,10-dimethylenecyclodec-5-enol, whereas the SC-CO2 method resulted in extracts containing a proportion of phytonutrients. Gas chromatography-mass spectrometry (GC-MS) analysis was conducted on the extract samples extracted by both the SC-CO_2 and hydrodistillation (HD) methods. The relative percentage of each detected component was determined by comparing its peak area to the total peak area. The specific results are detailed in Table 3. In total, the extracts with SC-CO_2 method detected 38 chemical components, while the HD method identified 62 components. The SC-CO_2 effectively isolates volatile substances at low boiling points, preventing the volatilization of heat-sensitive components. As a result, lipids in *Eleutherococcus senticosus* can be extracted without undergoing oxidation or decomposition that can occur at high temperatures during hydrodistillation. Conversely, the hydrodistillation method can extract volatile compounds, including those with high polarity and large molecular weight. In contrast, the SC-CO2 system struggles to extract highly polar or large-molecular-weight compounds, leading to the exclusion of certain constituents from the analysis.

Table 3
GC-MS results of the chemical composition of *Eleutherococcus senticosus* extracts.

No [a]	Components	RI [b]	ID [c]	Molecular formula	CAS number	RA [d] (%)	
						Supercritical CO_2 extraction	Hydrodistillation
1	dl-α-Tocopherol		MS[c]	$C_{29}H_{50}O_2$	0010191-41-0	nd[e]	1.86%
2	3,7,11,15-Tetramethyl-2-hexadecen-1-ol		MS	$C_{20}H_{40}O$	0102608-53-7	0.99%	0.90%
3	1-Heptatriacotanol		MS	$C_{37}H_{76}O$	0105794-58-9	8.11%	1.65%
4	Cedrene			$C_{15}H_{24}$	0011028-42-5	0.29%	nd
5	n-Hexane		MS	C_6H_{14}	0000110-54-3	0.04%	0.06%
6	1,6,10,14-Hexadecatetraen-3-ol, 3,7,11,15-tetramethyl-, (E, E)-		MS	$C_{20}H_{34}O$	0001113-21-9	nd	0.44%
7	5,9,13-Pentadecatrien-2-one, 6,10,14-trimethyl-, (E, E)-	1916	RI, MS	$C_{18}H_{30}O$	0001117-52-8	nd	0.27%
8	δ-Tocopherol	2968	RI, MS	$C_{27}H_{46}O_2$	0000119-13-1	nd	0.19%
9	1-(2-Hydroxypropan-2-yl)-3a-methyl-6,10-dimethylidene-2,3,4,5,7,8,9,11,12,12a-decahydro-1H-cyclopenta [11] annulene-5,9-diol		MS	$C_{20}H_{34}O_3$	1246094-62-1	0.36%	0.83%
10	((8R,8aS)-8-Isopropyl-5-methyl-3,4,6,7,8,8a-hexahydronaphthalen-2-yl) methanol		MS	$C_{15}H_{24}O$	0135118-52-4	nd	0.30%
11	Tau-Cadinol acetate		MS	$C_{17}H_{28}O_2$	0149197-48-8	nd	0.48%
12	Phytol	2127	RI, MS	$C_{20}H_{40}O$	0000150-86-7	12.42%	8.69%
13	2(4H)-Benzofuranone, 5,6,7,7a-tetrahydro-4,4,7a-trimethyl-, (R)-	2316	RI, MS	$C_{11}H_{16}O_2$	0017092-92-1	1.70%	nd
14	6,9,12,15-Docosatetraenoic acid, methyl ester		MS	$C_{23}H_{38}O_2$	0017364-34-0	0.37%	nd
15	cis-13-Eicosenoic acid		MS	$C_{20}H_{38}O_2$	0017735-94-3	1.23%	0.05%
16	(1R,2S,6S,7S,8S)-8-Isopropyl-1-methyl-3-methylenetricyclo [4.4.0.02,7] decane-rel-	1420	RI, MS	$C_{15}H_{24}$	0018252-44-3	7.79%	4.58%
17	1,3,6,10-Cyclotetradecatetraene, 3,7,11-trimethyl-14-(1-methylethyl)-, [S- (E, Z, E,	1847	RI, MS	$C_{20}H_{32}$	0001898-13-1	1.53%	1.19%

a Compounds from the DB-5 capillary column, in order of elusion.

b Retention indices relative to C_{11}–C_{30} n-alkanes on DB-5 capillary column.

c. Validated by reference to the weight data from the NIST17 Mass Spectrum Library.

d Percentage of relative surface (maximum area in relation to total maximum area, %).

e Not detected.

No [a]	Components	RI [b]	ID[c]	Molecular formula	CAS number	RA [d] (%)	
						Supercritical CO_2 extraction	Hydrodistillation
	E)]-						
18	5-Benzofuranacetic acid, 6-ethenyl-		MS	$C_{16}H_{20}O_4$	0019892-19-4	0.45%	nd
19	Cyclohexene, 4-ethenyl-4-methyl-3-(1-methylethenyl)-1-(1-methylethyl)-, (3R-trans)-	1340	RI, MS	$C_{15}H_{24}$	0020307-84-0	3.07%	3.81%
20	Levomenol		MS	$C_{15}H_{26}O$	0023089-26-1	nd	5.29%
21	1-Hexadecanol, 2-methyl-		MS	$C_{17}H_{36}O$	0002490-48-4	nd	0.14%
22	Thunbergol	2094	RI, MS	$C_{20}H_{34}O$	0025269-17-4	1.04%	0.69%
23	Estra-1,3,5(10)-trien-17β-ol		MS	$C_{18}H_{24}O$	0002529-64-8	1.09%	0.74%
24	1,3,6,10-Dodecatetraene, 3,7,11-trimethyl-, (Z, E)-	1491	MS	$C_{15}H_{24}$	0026560-14-5	nd	0.96%
25	β-Acorenol		MS	$C_{15}H_{26}O$	0028400-11-5	0.19%	nd
26	Epoxylathyrol		MS	$C_{20}H_{30}O_5$	0028649-60-7	0.11%	0.09%
27	cis-β-Farnesene	1660	RI, MS	$C_{15}H_{24}$	0028973-97-9	2.35%	1.36%
28	γ-Elemene	1431	RI, MS	$C_{15}H_{24}$	0029873-99-2	nd	0.71%
29	γ-Muurolene	1478	RI, MS	$C_{15}H_{24}$	0030021-74-0	0.37%	0.89%
30	(S,1Z,6Z)-8-Isopropyl-1-methyl-5-methylenecyclodeca-1,6-diene	1451	RI, MS	$C_{15}H_{24}$	0317819-80-0	0.46%	2.36%
31	(1R,3aS,8aS)-7-Isopropyl-1,4-dimethyl-1,2,3,3a,6,8a-hexahydroazulene		MS	$C_{15}H_{24}$	0036577-33-0	nd	1.17%
32	cis-3,14-Clerodadien-13-ol		MS	$C_{20}H_{34}O$	0374925-73-2	nd	0.29%
33	1H-Benzocycloheptene, 2,4a,5,6,7,8,9,9a-octahydro-3,5,5-trimethyl-9-methylene-, (4aS-cis)-	1445	MS	$C_{15}H_{24}$	0003853-83-6	0.15	0.64%
34	Ageratrio		MS	$C_{15}H_{24}O_3$	0038022-97-8	0.81%	nd
35	Copaene	1353	RI,	$C_{15}H_{24}$	0003856-	nd	0.17%

a Compounds from the DB-5 capillary column, in order of elusion.

b Retention indices relative to C_{11}–C_{30} n-alkanes on DB-5 capillary column.

c. Validated by reference to the weight data from the NIST17 Mass Spectrum Library.

d Percentage of relative surface (maximum area in relation to total maximum area, %).

e Not detected.

No [a]	Components	RI [b]	ID [c]	Molecular formula	CAS number	RA [d] (%)	
						Supercritical CO_2 extraction	Hydrodistillation
			MS		25-5		
36	β-Longipinene	1402	RI, MS	$C_{15}H_{24}$	0041432-70-6	nd	0.08%
37	2H-1-Benzopyran, 3,4,4a,5,6,8a-hexahydro-2,5,5,8a-tetramethyl-, (2α,4aα,8aα)-		MS	$C_{13}H_{22}O$	0041678-32-4	nd	0.08%
38	9,19-Cyclolanost-24-en-3-ol, (3β)-		MS	$C_{30}H_{50}O$	0000469-38-5	nd	0.15%
39	Azulene, 1,4-dimethyl-7-(1-methylethyl)-		MS	$C_{15}H_{18}$	0000489-84-9	nd	0.85%
40	1,3-Cyclohexadiene, 5-(1,5-dimethyl-4-hexenyl)-2-methyl-, [S- (R*, S*)]-	1494	RI, MS	$C_{15}H_{24}$	0000495-60-3	nd	2.72%
41	2-Pentadecanone, 6,10,14-trimethyl-		MS	$C_{18}H_{36}O$	0000502-69-2	nd	0.69%
42	β-Bisabolene	1509	RI, MS	$C_{15}H_{24}$	0000495-61-4	2.82%	nd
43	14-Hydroxycaryophyllene		MS	$C_{15}H_{24}O$	0050277-33-3	0.85%	nd
44	Neophytadiene	1915	RI, MS	$C_{20}H_{38}$	0000504-96-1	2.21%	1.29%
45	(2R,8R,8aS)-8,8a-Dimethyl-2-(prop-1-en-2-yl)-1,2,3,7,8,8a-hexahydronaphthalene		MS	$C_{15}H_{22}$	0005090-61-9	nd	2.58%
46	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, [1S-(1α,2β,4β)]-	1390	RI, MS	$C_{15}H_{24}$	0000515-13-9	4.39%	5.38%
47	2-((2R,4aR,8aS)-4a-Methyl-8-methylenedecahydronaphthalen-2-yl) prop-2-en-1-ol	1756	RI, MS	$C_{15}H_{24}O$	0000515-20-8	nd	0.46%
48	(E)-1-Methyl-4-(6-methylhept-5-en-2-ylidene) cyclohex-1-ene	1533	RI, MS	$C_{15}H_{24}$	0053585-13-0	nd	0.68%
49	Octadecane, 3-ethyl-5-(2-ethylbutyl)-		MS	$C_{26}H_{54}$	0055282-12-7	nd	0.33%
50	Kaur-16-ene	2040	RI, MS	$C_{20}H_{32}$	0000562-28-7	0.67%	0.81%
51	7,10-Octadecadienoic acid, methyl ester		MS	$C_{19}H_{34}O_2$	0056554-24-6	nd	0.07%
52	α-Vetivol		MS	$C_{15}H_{24}O$	0057422-86-3	nd	0.90%
53	Pentacosane		MS	$C_{25}H_{52}$	0000629-	nd	0.65%

a Compounds from the DB-5 capillary column, in order of elusion.

b Retention indices relative to C_{11}–C_{30} n-alkanes on DB-5 capillary column.

c. Validated by reference to the weight data from the NIST17 Mass Spectrum Library.

d Percentage of relative surface (maximum area in relation to total maximum area, %).

e Not detected.

No [a]	Components	RI [b]	ID [c]	Molecular formula	CAS number	RA [d] (%)	
						Supercritical CO_2 extraction	Hydrodistillation
					99-2		
54	Cyclohexanemethanol, 4-ethenyl-α, α, 4-trimethyl-3-(1-methylethenyl)-, [1R-(1α,3α,4β)]-	1547	RI, MS	$C_{15}H_{26}O$	0000639-99-6	nd	0.33%
55	Hexadecanoic acid, ethyl ester	1994	RI, MS	$C_{18}H_{36}O_2$	0000628-97-7	0.29%	nd
56	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1,7-trimethyl-4-methylene-, [1ar-(1aα,4aα,7β,7aβ,7bα)]-	1577	RI, MS	$C_{15}H_{24}O$	0006750-60-3	0.67%	1.85%
57	17-Pentatriacontene		MS	$C_{35}H_{70}$	0006971-40-0	5.92%	2.05%
58	Bicyclo [9.3.1] pentadeca-3,7-dien-12-ol, 4,8,12,15,15-pentamethyl-, [1R-(1R*,3E,7E,11R*,12R*)]-		MS	$C_{20}H_{34}O$	0070000-19-0	nd	1.23%
59	γ-Tocopherol		MS	$C_{28}H_{48}O_2$	0007616-22-0	nd	1.62%
60	3,7,11,15-Tetramethylhexadec-2-en-1-yl acetate		MS	$C_{22}H_{42}O_2$	0076337-16-1	nd	0.94%
61	(-)-Spathulenol		MS	$C_{15}H_{24}O$	0077171-55-2	nd	1.35%
62	(3R,3aR,7R,8aS)-3,8,8-Trimethyl-6-methyleneoctahydro-1H-3a,7-methanoazulene	1434	RI, MS	$C_{15}H_{24}$	0079120-98-2	nd	3.91%
63	Lanosterol		MS	$C_{30}H_{50}O$	0000079-63-0	1.05%	0.84%
64	(1R,7S, E)-7-Isopropyl-4,10-dimethylenecyclodec-5-enol		MS	$C_{15}H_{24}O$	0081968-62-9	5.00%	9.65%
65	Hexacosyl acetate		MS	$C_{28}H_{56}O_2$	0000822-32-2	nd	1.07%
66	β-Sitosterol		MS	$C_{29}H_{50}O$	0000083-46-5	nd	0.29%
67	Stigmasterol		MS	$C_{29}H_{48}O$	0000083-48-7	8.72%	3.90%
68	Caryophyllene	1419	RI, MS	$C_{15}H_{24}$	0000087-44-5	5.01%	4.15%
69	Isospathulenol	2225	RI, MS	$C_{15}H_{24}O$	0088395-46-4	9.79%	8.13%
70	β-Guaiene	1492	RI, MS	$C_{15}H_{24}$	0000088-84-6	nd	0.09%

a Compounds from the DB-5 capillary column, in order of elusion.

b Retention indices relative to C_{11}–C_{30} n-alkanes on DB-5 capillary column.

c. Validated by reference to the weight data from the NIST17 Mass Spectrum Library.

d Percentage of relative surface (maximum area in relation to total maximum area, %).

e Not detected.

No [a]	Components	RI [b]	ID[c]	Molecular formula	CAS number	RA [d] (%)	
						Supercritical CO_2 extraction	Hydrodistillation
71	4,8,12,16-Tetramethylheptadecan-4-olide		MS	$C_{21}H_{40}O_2$	0096168-15-9	0.59%	0.12%
72	1,6,10,14,18,22-Tetracosahexaen-3-ol, 2,6,10,15,19,23-hexamethyl-, (all-E)- (±)-		MS	$C_{30}H_{50}O$	0097232-74-1	3.65%	nd
a Compounds from the DB-5 capillary column, in order of elusion.							
b Retention indices relative to C_{11}–C_{30} n-alkanes on DB-5 capillary column.							
c. Validated by reference to the weight data from the NIST17 Mass Spectrum Library.							
d Percentage of relative surface (maximum area in relation to total maximum area, %).							
e Not detected.							

3.5 Results of antioxidant activity of *Eleutherococcus senticosus* extracts

Phytol is one of the important components of *Eleutherococcus senticosus* and are commonly used as antioxidants (Garzoli et al. 2021). The results of ESE's ability to clear 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radicals are illustrated in the Fig. 6a. The clearance level shows a positive correlation with concentration in the range of 0.39 to 50 mg/mL. At a concentration of 25 mg/mL, the scavenging rate of DPPH free radicals was 69.23%. This rate stabilized as the concentration continued to increase. A comparison between ESE and vitamin C (Vc) at equivalent concentrations revealed that ESE exhibits effective DPPH free radical scavenging activity, although its efficacy is lower than that of Vc. The scavenging rate of ESE against hydroxyl radicals is presented in the Fig. 6b. This rate also demonstrated a positive correlation with concentration, ranging from 0.048 to 3.13 mg/mL. At a concentration of 0.78 mg/mL, the scavenging rate of hydroxyl radicals reached 71.43%. In a manner analogous to DPPH scavenging, this rate exhibited stability with increasing concentration. When compared to Vc at the same concentrations, ESE showed a better scavenging ability for hydroxyl radicals; however, it was still weaker than that of Vc. The ESE extracted from SC-CO_2 showed strong scavenging ability on both DPPH free radical and hydroxyl free radical.

4. Conclusion

In this work, we utilized supercritical CO_2 (SC-CO_2) to extract the extracts from *Eleutherococcus senticosus*. A single-factor experiment was conducted to investigate the effects of extraction pressure, temperature, and duration on the process. The extraction conditions were optimized using the Face-Centered Central Composite Design (FCCCD) method, resulting in a yield of 1.88 ± 0.05% when reacted at 30 MPa and 60 ^{o}C for 2 h. Compared to the traditional hot distillation method, SC-CO_2 extraction of the extracts offers a higher yield, faster efficiency and effectively prevents the oxidation and volatilization of heat-sensitive components, ensuring full utilization of the raw material. gas chromatography-mass spectrometry (GC-MS) analysis revealed that the component with the highest concentration of the extract was phytol, accounting for 12.42%. Furthermore, the extracts exhibited strong antioxidant activity against various radicals, including DPPH free radicals. This extraction method holds significant potential for enhancing the economic value of the extracts and expanding their industrial applications.

Declarations

Competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

Funding

Science and Technology Project of Henan Tobacco Industry Co., LTD (AW2023004), and the Key Research and Development Plan Project of Heilongjiang Province (2022ZX02C13).

Author Contribution

Zening Wang, Gaolei Xi, Changtong Lu, Yibo Ning, Xueying Cao, Shuqing Ao: Conceptualization, writing, preparation of the essential oil, data curation and statistical analyses. Zhifei Chen, Yongzhen Zhao, Tao Jia, Xiuhua Zhao: Conceptualization, visualization, supervision, writing, reviewing, and editing.

Acknowledgment

This work was supported by the Science and Technology Project of Henan Tobacco Industry Co., LTD (AW2023004), and the Key Research and Development Plan Project of Heilongjiang Province (2022ZX02C13).

Data Availability

All data generated or analyzed during this study are available from the corresponding author upon reasonable request.

References

1. Bocevska M, Sovová H. (2007). Supercritical CO_2 extraction of essential oil from yarrow. *The Journal of Supercritical Fluids*, 40(3), 360–367. https://doi.org/10.1016/j.supflu.2006.07.014
2. Chen XQ, Jia XD, Yang S, Zhang GF, Li AL, Du P, Liu LB, Li C. (2022). Optimization of ultrasonic-assisted extraction of flavonoids, polysaccharides, and *Eleutherococcus senticosus* sides from *Dendranthema indicum* using response surface methodology in development of health wine. *Lwt-Food Science and Technology*, 165, 113725. https://doi.org/10.1016/j.lwt.2022.113725
3. Chen F, Wang Y, Wang K, Chen J, Jin K, Peng K, Lin Q. (2023). Effects of Litsea cubeba essential oil on growth performance, blood antioxidation, immune function, apparent digestibility of nutrients, and fecal microflora of pigs. *Frontiers in Pharmacology*, 14, 1166022. https://doi.org/10.3389/fphar.2023.1166022
4. Cui W, Xu RJ, Li XQ, Yang JL, Xu P, Zhang ZT, Yu Z, Adiges S. (2024). Research on the supercritical CO_2 extraction process of Hetian Rose essential oil. *Processes*, 12(7), 1396. https://doi.org/10.3390/pr12071396
5. Dashtian K, Kamalabadi M, Ghoorchian A, Ganjali M R, Rahimi-Nasrabadi M. (2024). Integrated supercritical fluid extraction of essential oils. *Journal of Chromatography A*, 1733, 465240. https://doi.org/10.1016/j.chroma.2024.465240
6. Dimitrijević S, Milić M, Tadić V, Maksimović S, Filipović V, Dimitrijević-Branković S, Miljković M, Salamon I. (2024). Black cumin essential oil as a valuable source of bioactive compounds: Evaluation of the conventional vs. modern extraction technique. *Sustainable Chemistry and Pharmacy*, 37, 101390. https://doi.org/10.1016/j.scp.2023.101390
7. Garzoli S, Laghezza Masci V, Franceschi S, Tiezzi A, Giacomello P, Ovidi E. (2011). Headspace/GC–MS analysis and investigation of antibacterial, antioxidant and cytotoxic activity of essential oils and hydrolates from *Rosmarinus officinalis* L. and *Lavandula angustifolia* Miller. *Foods*, 10(8), 1768. https://doi.org/10.3390/foods10081768
8. Guo T, Hao Q, Nan Z, Wei C, Liu J, Huang F, Wan C. (2022). Green extraction and separation of *Dendranthema indicum* essential oil by supercritical carbon dioxide extraction combined with molecular distillation. *Journal of Cleaner Production*, 376, 134208. https://doi.org/10.1016/j.jclepro.2022.134208
9. Gómez-L HÉ, P.-E, Barat JM, Jiménez MC, González-Bello C, Fernández-Segovia I. (2025). Antimicrobial activity of essential oil components against *Escherichia coli* depends on the food components present in a food matrix. *Food Microbiology*, 125, 104638. https://doi.org/10.1016/j.fm.2024.104638
10. Haloui I, Meniai AH. (2017). Supercritical CO_2 extraction of essential oil from *Algerian Argan* (*Argania spinosa* L.) seeds and yield optimization. *International Journal of Hydrogen Energy*, 42(17), 12912–12919. https://doi.org/10.1016/j.ijhydene.2016.12.012

11. Jia N, Shen ZJ, Zhao SJ, Wang YL, Pei CX, Huang DM, Wang XM, Wu YC, Shi SH, He YC. (2023). *Eleutherococcus senticosus* side E from pre-treatment of *Acanthopanax senticosus* (Rupr. etMaxim.) Harms ameliorates high-altitude-induced heart injury by regulating NLRP3 inflammasome-mediated pyroptosis via NLRP3/caspase-1 pathway. *International Immunopharmacology*, 121, 110423. https://doi.org/10.1016/j.intimp.2023.110423
12. Khalati E, Oinas P, Favén L. (2023). Techno-economic and safety assessment of supercritical CO_2 extraction of essential oils and extracts. *Journal of CO_2 Utilization*, 74, 102547. https://doi.org/10.1016/j.jcou.2023.102547
13. Khwaza V, Aderibigbe BA. (2025). Antibacterial activity of selected essential oil components and their derivatives: A Review. *Antibiotics*, 14(1), 68. https://doi.org/10.3390/antibiotics14010068
14. Liu RX, Chu XL, Su JQ, Fu X, Kan QB, Wang XY, Zhang XY. (2021). Enzyme-assisted ultrasonic extraction of total flavonoids from *Acanthopanax senticosus* and their enrichment and antioxidant properties. *Processes*, 9(10), 1708. https://doi.org/10.3390/pr9101708
15. Li XJ, Chen C, Leng AJ, Qu JL. (2021). Advances in the extraction, purification, structural characteristics and biological activities of *Eleutherococcus senticosus* polysaccharides: a promising medicinal and edible resource with development value. *Frontiers in Pharmacology*, 12, 753007. https://doi.org/10.3389/fphar.2021.753007
16. Lu CR, Li HY, Li C, Chen B, Shen YH. (2018). Chemical composition and radical scavenging activity of *Amygdalus pedunculata* Pall leaves' essential oil. *Food and Chemical Toxicology*, 119, 368–374. https://doi.org/10.1016/j.fct.2018.02.012
17. Ma JH, Lai Y, He GX, Chen YY, Ding S, Li XM, Yang CC, Li MW, Zhang BH, Zhang DQ. (2025). Superimposed effect of plant essential oil constituents and their biomedical application. *Industrial Crops and Products*, 224, 120362. https://doi.org/10.1016/j.indcrop.2024.120362
18. Mangalagiri NP, Panditi SK, Jeevigunta NLL. (2021). Antimicrobial activity of essential plant oils and their major components. *Heliyon*, 7(4), e06835. https://doi.org/10.1016/j.heliyon.2021.e06835
19. Mu LT, Zhang QD, Sun SY, Liu B, Zhang Y, Zhang XR, Sun CH. (2022). Study on the technology of efficient extraction of *Eleutherococcus senticosus* side E from *Acanthopanax senticosus* by green solvent DES. *Phytochemical Analysis*, 33(6), 879–885. https://doi.org/10.1002/pca.3144
20. Sana SS, Li HZ, Zhang ZJ, Sharma M, Usmani Z, Hou TY, Netala VR, Wang X, Gupta VK. (2021). Recent advances in essential oils-based metal nanoparticles: A review on recent developments and biopharmaceutical applications. *Journal Of Molecular Liquids*, 333, 115951. https://doi.org/10.1016/j.molliq.2021.11595
21. Shen QJ, Sun JY, Pan JN, Yu T, Zhou WW. (2024). Synergistic antimicrobial potential of essential oil nanoemulsion and ultrasound and application in food industry: A review. *Innovative Food Science & Emerging Technologies*, 98, 103867. https://doi.org/10.1016/j.ifset.2024.103867
22. Uribe JaR, Perez JIN, Kauil HC, Rubio GR, Alcocer CG. (2011). Extraction of oil from chia seeds with supercritical CO_2. *J Supercrit Fluid*, 56(2), 174–178. https://doi.org/10.1016/j.supflu.2010.12.007
23. Uwineza PA, Waskiewicz A. (2020). Recent advances in supercritical fluid extraction of natural bioactive compounds from natural plant materials. *Molecules*, 25(17), 3847. https://doi.org/10.3390/molecules25173847
24. Verdeguer M, Sánchez-Moreiras AM, Araniti F. (2020). Phytotoxic effects and mechanism of action of essential oils and terpenoids. *Plants*, 9(11), 1571. https://doi.org/10.3390/plants9111571
25. Wang YH, Meng YH, Zhai CM, Wang M, Avula B, Yuk J, Smith KM, Isaac G, Khan IA. (2019). The chemical characterization of *Eleutherococcus senticosus* and Ci-wu-jia Tea using UHPLC-UV-QTOF/MS. *International Journal of Molecular Sciences*, 20(3), 475. https://doi.org/10.3390/ijms20030475
26. Wang ZL, Pan HY, Xu J, Chang YH, Liu C, Zhang Y, Yang H, Duan CJ, Huang J, Fu YJ. (2022). A sustainable and integrated natural surfactant mediated microwave-assisted extraction technique enhances the extraction of phytochemicals from plants. *Industrial Crops and Products*, 184, 115043. https://doi.org/10.1016/j.indcrop.2022.115043
27. Zhang HX, Huang T, Liao XN, Zhou YH, Chen SX, Chen J, Xiong WM. (2022). Extraction of camphor tree essential oil by hydrodistillation and supercritical CO_2 extraction. *Molecules*, 27(17), 5385. https://doi.org/10.3390/molecules27175385
28. Zhang SK, Zhang H, Ding LW, Xia YX, Dai WX, Han XF, Siqin TY, You XL. 2023. Evaluation and selection of excellent provenances of *Eleutherococcus senticosus*. Forests. 14(7):1359. https://doi.org/10.3390/f14071359

Figures

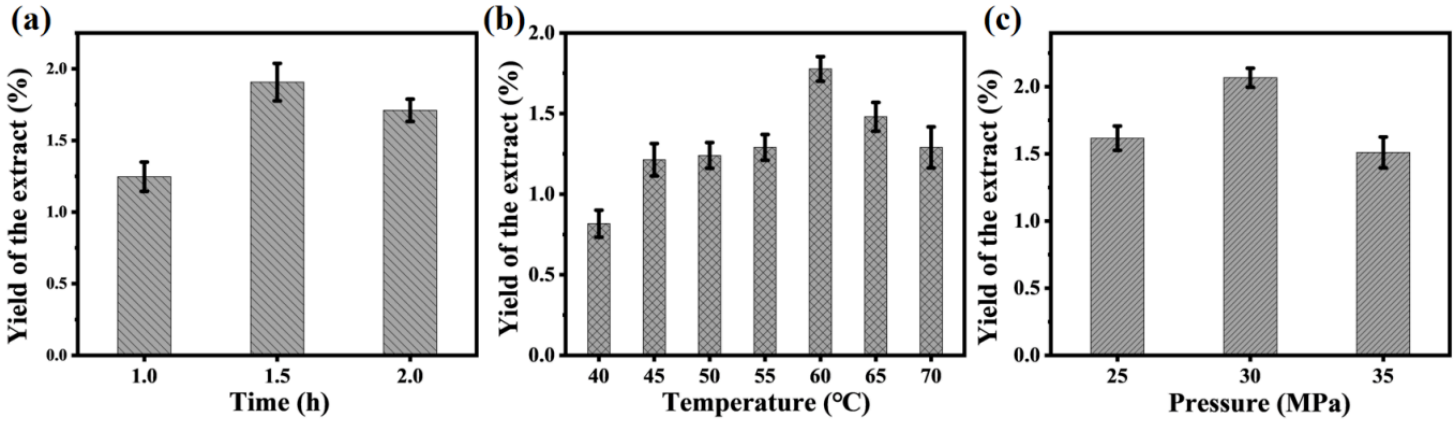

Figure 1

Three main factors influencing the extracts by Supercritical CO_2 extraction of *Eleutherococcus senticosus* were studied. Extraction time (a), Extraction temperature (b), Extraction pressure (c).

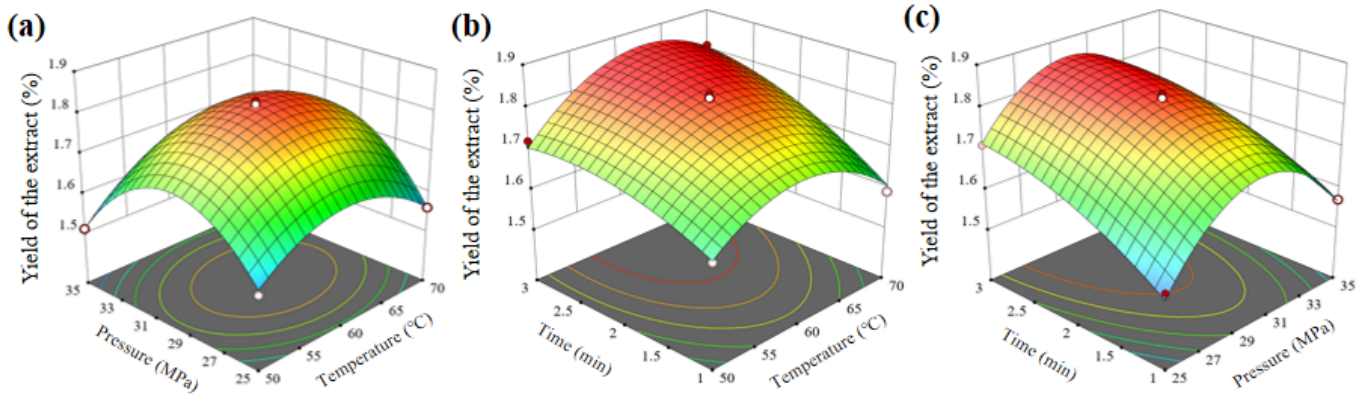

Figure 2

The three-dimensional graph illustrates the interaction of extraction time, extraction temperature and extraction pressure on the *Eleutherococcus senticosus* extracts yield.

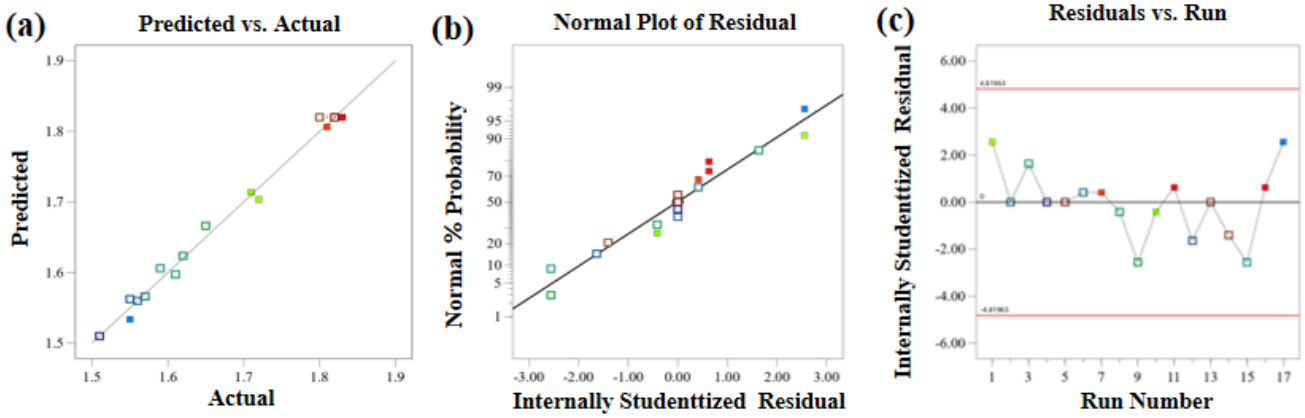

Figure 3

Diagnosis plots for BBD model adequacy. normal probability distribution of the residuals Predicted versus actual (a), Normal regression of residuals (b), and Residual observation sequence diagram (c).

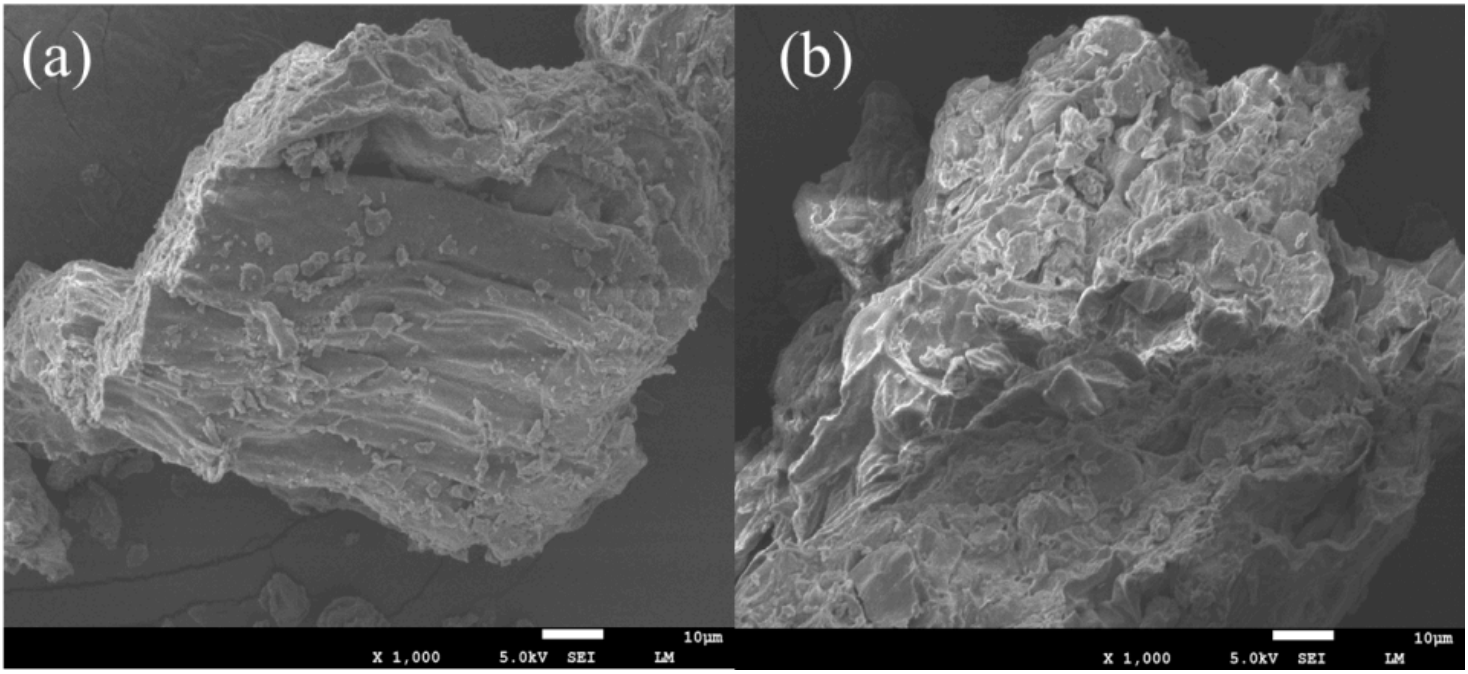

Figure 4

SEM image of *Eleutherococcus senticosus* power (a), *Eleutherococcus senticosus* after supercritical CO_2 extraction (b).

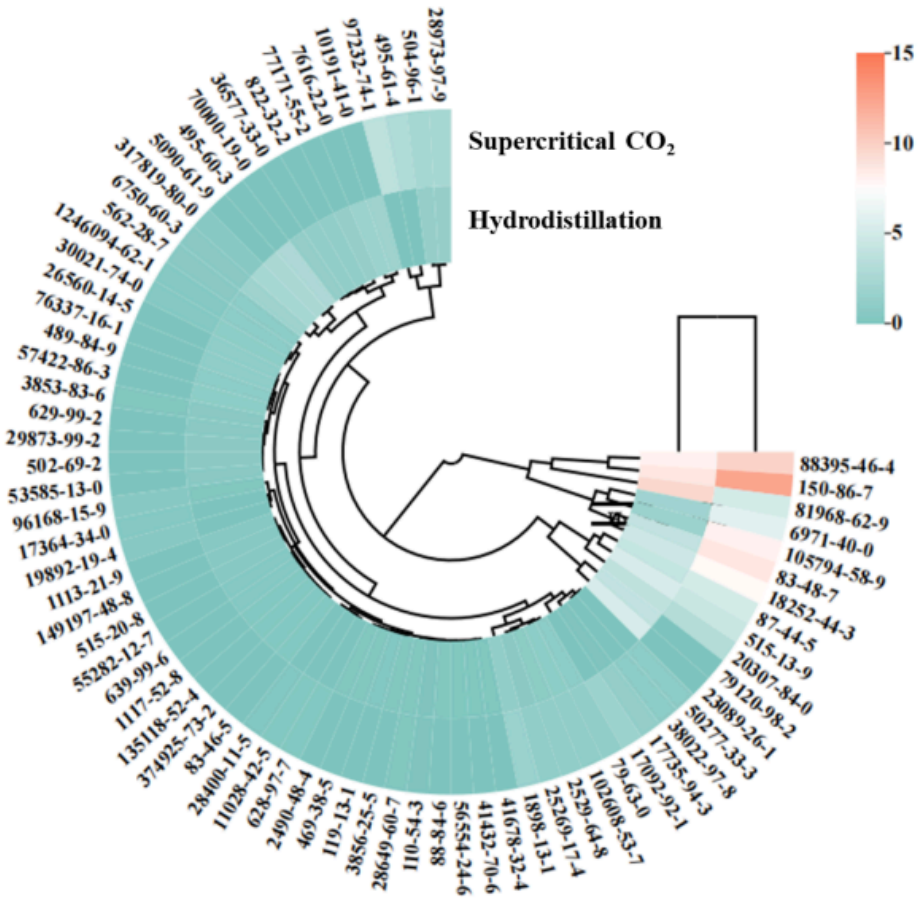

Figure 5

The cyclic clustering heatmap of the extracts components extracted from *Eleutherococcus senticosus* using HD and SC-CO_2 methods. The X-axis represents the extraction method, and the Y-axis represents the CAS number of the extracts component.

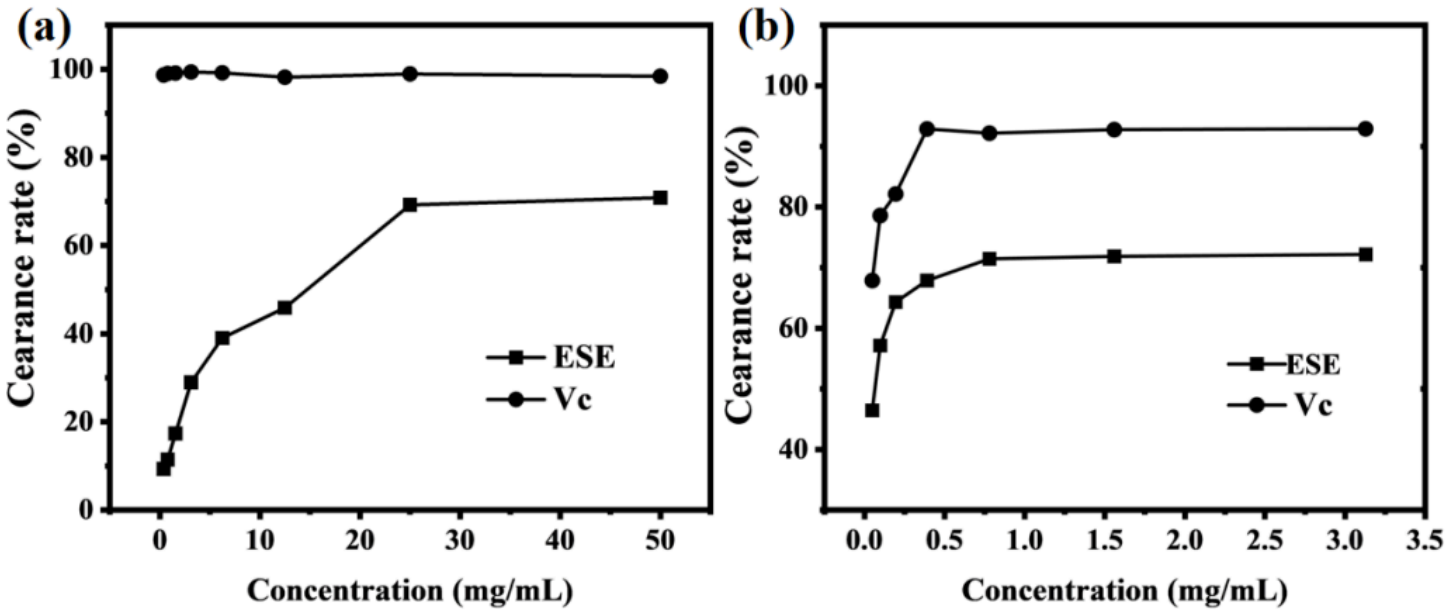

Figure 6

DPPH radical scavenging capacity of *Eleutherococcus senticosus* extracts and Vc (a), Hydroxyl radical scavenging capacity of *Eleutherococcus senticosus* extracts and Vc (b).