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Determination of chemical composition and evaluation of the antioxidant activity of alcoholic extracts from the fruits of *Sterculia lanceolata* Cav. In Việt Nam

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Abstract

Sterculia lanceolata Cav. is a tropical medicinal plant distributed in several Southeast Asian countries and traditionally utilized for the treatment of various ailments. The present study investigated the phytochemical constituents and antioxidant activity of the ethanolic fruit extract of *Sterculia lanceolata* collected in Thai Nguyen Province, Viet Nam. Qualitative phytochemical screening confirmed the presence of several major groups of secondary metabolites, including flavonoids, tannins, alkaloids, and saponins. Chemical profiling by GC/FID and GC/MS analyses tentatively identified more than 70 compounds belonging to different chemical classes such as phenolic derivatives, alkaloid-related compounds, heterocyclic nitrogen compounds, flavonoid-related metabolites, aromatic amides, esters, and steroid-related constituents. Among the detected compounds, phenolic derivatives and nitrogen-containing heterocycles represented important components of the extract. The antioxidant activity of the ethanolic extract was evaluated using the DPPH radical scavenging assay. The extract demonstrated concentration-dependent free radical scavenging activity, although lower than that of vitamin C, indicating considerable antioxidant potential. The observed activity may be associated with the combined effects of phenolic and flavonoid compounds together with other bioactive metabolites detected in the extract. These findings provide scientific evidence supporting the potential utilization of *Sterculia lanceolata* fruits as a natural source of antioxidant compounds for pharmaceutical and functional food applications.

Keywords: Antioxidant activity; DPPH assay; Ethanolic extract; GC/MS analysis; Phytochemical constituents; *Sterculia lanceolata*Cav; Secondary metabolites; Tropical medicinal plant

1. Introduction

Sterculia lanceolata Cav. is a tropical plant species belonging to the family Malvaceae (formerly Sterculiaceae), distributed in several Southeast Asian countries, including Viet Nam, Laos, Thailand, and southern China. The species commonly grows in tropical forests and mountainous regions and has been traditionally utilized in folk medicine for the treatment of inflammation, fever, digestive disorders, and other common ailments [1]. In recent years, increasing attention has been directed toward the phytochemical constituents and biological activities of species within the genus *Sterculia*, particularly their antioxidant potential and medicinal applications [2].

The fruits of *Sterculia lanceolata* are characterized by follicular capsules containing numerous seeds surrounded by brightly colored arils. Previous phytochemical investigations on related *Sterculia* species revealed the presence of diverse secondary metabolites, including flavonoids, phenolic acids, tannins, triterpenoids, sterols, alkaloids, and glycosides [2], [3]. These compounds are known to exhibit important biological properties, especially antioxidant, antimicrobial, anti-inflammatory, and antidiabetic activities. Ethanol has frequently been employed as an effective extraction solvent for recovering phenolic and flavonoid compounds from medicinal plants due to its high extraction efficiency and low toxicity [4].

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Several studies on the genus *Sterculia* demonstrated that ethanolic extracts from different plant parts possess remarkable free radical scavenging activity through DPPH, ABTS, and FRAP assays. The antioxidant effects were closely associated with high levels of total phenolic and flavonoid contents in the extracts [3], [5]. In addition, advanced chromatographic analyses, including LC-MS/MS and GC-MS, identified numerous bioactive compounds such as gallic acid, caffeic acid, quercetin, ferulic acid, protocatechuic acid, and β-sitosterol derivatives from *Sterculia* species, which contribute significantly to antioxidant and pharmacological activities [5].

Recent investigations also suggested that fruit-derived extracts of *Sterculia* species may have promising applications in pharmaceutical and functional food industries because of their ability to inhibit oxidative stress and neutralize reactive oxygen species (ROS) [5]. Despite the growing interest in the biological activities of the genus, information concerning the phytochemical composition and antioxidant activity of ethanol extracts obtained from the fruits of *Sterculia lanceolata*collected in Viet Nam remains scarce. Therefore, the present study aimed to investigate the chemical constituents of the ethanol extract of *Sterculia lanceolata* fruits using GC–MS analysis and to evaluate its antioxidant activity, thereby providing scientific evidence for the potential utilization of this species as a natural source of bioactive compounds for pharmaceutical and nutraceutical applications.

2. Materials and methods

2.1. Materials

Fresh fruits of *Sterculia lanceolata* Cav. were harvested in March 2026 from wild populations growing in Thai Nguyen Province, Viet Nam. The collected samples were thoroughly washed, shade-dried at ambient temperature, ground into fine powder, and stored in sealed containers until further phytochemical and antioxidant analyses were conducted. Ethanol extracts were subsequently prepared for chemical profiling and evaluation of antioxidant potential.

The botanical identity of the plant was confirmed by Sỹ Danh Thường using conventional taxonomic procedures and comparison with standard botanical references. A voucher specimen was archived at the Biological Museum, Faculty of Biology, Thai Nguyen University of Education under the accession number TNUE-SLC2026-05.

2.2. Methods

2.2.1. Preparation of Ethanol Extract

Fresh fruits of *Sterculia lanceolata* Cav. were carefully cleaned with distilled water to eliminate adhering contaminants and then dried in a hot-air oven at 55°C until a stable weight was obtained. After drying, the fruits were pulverized into a uniform fine powder using a mechanical grinder. Approximately 100 g of the powdered material was soaked in 99% ethanol at a material-to-solvent ratio of 1:10 (w/v) and kept at ambient temperature for 72 h with intermittent agitation to enhance the extraction process. The extract mixture was subsequently filtered through Whatman No. 1 filter paper to remove insoluble residues. The filtrate was concentrated under vacuum using a rotary evaporator at 40°C, yielding the crude ethanolic extract. The obtained extract was preserved in sealed containers at 4°C prior to phytochemical screening and antioxidant activity evaluation. The ethanolic extract of *Sterculia lanceolata* fruits was anticipated to contain a variety of secondary metabolites contributing to its potential antioxidant properties.

2.2.2. Qualitative Phytochemical Analysis

The fruits of *Sterculia lanceolata* Cav. were thoroughly washed with distilled water to remove surface impurities and foreign materials. The cleaned samples were dried in a hot-air oven at 55°C until a constant mass was achieved. After complete drying, the fruit material was finely powdered using an electric grinder to obtain a uniform sample for extraction.

About 100 g of the powdered fruits was subjected to extraction with 99% ethanol using the maceration technique at a ratio of 1:10 (w/v). The extraction process was carried out at room temperature for 72 h with periodic shaking to improve the diffusion of phytochemicals into the solvent. The resulting mixture was filtered through Whatman No. 1 filter paper to separate the liquid extract from the plant residues.

The filtrate was concentrated under reduced pressure at 40°C using a rotary evaporator to obtain the crude ethanolic extract of *Sterculia lanceolata* fruits. The concentrated extract was transferred into airtight containers and stored at 4°C until further qualitative phytochemical investigations and antioxidant analyses were conducted. The obtained ethanolic extract was expected to contain several classes of bioactive secondary metabolites associated with antioxidant activity.

2.2.3. GC/FID and GC/MS Analysis

The crude ethanolic extract obtained from the fruits of *Sterculia lanceolata* Cav. was subjected to GC/FID and GC/MS analyses to determine the composition of volatile phytochemical constituents. After ethanol extraction and concentration under reduced pressure, the extract was partitioned with n-hexane in order to recover the volatile fraction. The n-hexane-soluble portion was then used for chromatographic evaluation. Gas chromatography–mass spectrometry (GC/MS) was conducted using a Hewlett Packard 5890 Series II gas chromatograph coupled to an HP 5971 MSD quadrupole mass spectrometer (Agilent Technologies, USA). Separation of compounds was achieved on an HP-5MS fused silica capillary column measuring 30 m × 0.25 mm with a film thickness of 0.25 µm and coated with a non-polar stationary phase. High-purity helium (99.99%) served as the carrier gas at a constant flow rate of 0.9 mL/min. The oven temperature program began at 50 °C and was held for 3 min, followed by a gradual increase to 200 °C at a rate of 3 °C/min. The temperature was then elevated to 240 °C at 10 °C/min and maintained for another 3 min, resulting in a total analytical time of about 60 min. Mass spectra were generated using electron impact ionization at 70 eV, and spectral acquisition was performed within a mass range of 30–600 amu. In addition, gas chromatography coupled with a flame ionization detector (GC-FID) was employed to support both qualitative and semi-quantitative analyses of the volatile compounds. Identification of the detected constituents was carried out by comparing retention indices and mass spectral profiles with reference data from established databases, including the NIST Chemistry WebBook as well as the Wiley NBS75K.L and NIST/EPA/NIH mass spectral libraries

2.2.4. Determination of Antioxidant Activity by DPPH Radical Scavenging Assay

The free radical scavenging activity of the ethanolic fruit extract of *Sterculia lanceolata* Cav. was assessed using the DPPH (1,1-diphenyl-2-picrylhydrazyl) assay based on the procedure described by Tabart et al. (2009) [6] with slight modifications. Serial concentrations of the extract (0.5, 1, 2, 4, 8, 16, 32, 64, and 128 µg/mL) were prepared in methanol prior to analysis. For each test, 100 µL of the prepared extract solution was added to 2.9 mL of freshly prepared 0.1 mM DPPH methanolic solution. The reaction mixtures were thoroughly mixed using a vortex shaker and then kept in the dark at room temperature for 30 min to facilitate the interaction between antioxidant compounds and DPPH radicals. Following incubation, absorbance measurements were taken at 517 nm using a UV–Visible spectrophotometer. The percentage of radical scavenging activity was calculated using the following equation: DPPH scavenging activity (%) = 100 x (Ac - As)/Ac.

where Ac represents the absorbance of the control solution containing DPPH without extract, while As denotes the absorbance of the reaction mixture containing the plant extract. The antioxidant potential of the extract was expressed as the IC_{50} value, corresponding to the concentration required to inhibit 50% of DPPH free radicals. All experiments were conducted in triplicate, and the results were presented as mean ± standard deviation.

3. Results and discussion

3.1. Qualitative Phytochemical Analysis

The qualitative phytochemical investigation of the ethanolic extract obtained from the fruits of *Sterculia lanceolata* Cav. revealed the presence of several important groups of secondary metabolites, including flavonoids, tannins, alkaloids, and saponins (Table 1). These classes of phytochemicals are widely recognized for their biological and pharmacological significance, particularly their antioxidant potential and protective effects against oxidative stress. Previous studies on species belonging to the genus *Sterculia* have similarly reported the occurrence of phenolic compounds, flavonoids, tannins, terpenoids, and alkaloids in ethanolic extracts, which were associated with considerable antioxidant activity [7–8].

Table 1 Qualitative phytochemical screening of ethanolic fruit extract of *Sterculia lanceolata*Cav.

No.	Compound Class	Phytochemical Test	Observation	Result
1	Alkaloids	Wagner's reagent	Brown precipitate	(+)
		Dragendorff's reagent	Orange precipitate	
2	Flavonoids	Cyanidin reaction	Orange-red coloration	(+)
		NaOH test	Intense yellow solution	
3	Tannins	$FeCl_3$ test	Greenish-brown coloration	(+)
4	Saponins	Frothing test	Stable foam formation	(+)

In the present study, positive phytochemical reactions were identified through characteristic precipitate formation and distinct color changes during standard screening procedures. Alkaloids produced brown and orange precipitates with Wagner's and Dragendorff's reagents, respectively, whereas flavonoids generated orange-red coloration in the cyanidin reaction and an intense yellow color in the NaOH assay. Tannins were confirmed by the appearance of a greenish-brown coloration after treatment with ferric chloride solution, while saponins were detected by stable froth formation in the frothing test.

The occurrence of flavonoids and tannins in the ethanolic fruit extract suggests a potential role in free radical scavenging activity because these compounds are capable of donating electrons or hydrogen atoms to neutralize reactive oxygen species. Likewise, alkaloids and saponins have been reported to exhibit antimicrobial, anti-inflammatory, and cytoprotective activities in medicinal plants [7,2]. Ethanol is considered an effective solvent for extracting both polar and moderately polar phytoconstituents, which may explain the diversity of metabolites detected in the present extract.

Comparable findings were reported in ethanolic extracts of *Sterculia quadrifida* and *Sterculia rubiginosa*, where flavonoids, tannins, alkaloids, phenolics, and terpenoid-related compounds were identified and correlated with antioxidant properties [2,8]. In addition, antioxidant investigations on *Sterculia cordata* demonstrated that ethanolic extracts rich in phenolic and flavonoid compounds exhibited strong radical scavenging capacity [7]. Therefore, the phytochemical profile observed in the ethanolic fruit extract of *Sterculia lanceolata* Cav. may contribute significantly to its antioxidant potential and other biological activities

3.2. GC/MS analysis of ethanolic extract of *Sterculia lanceolata* Cav.

GC/FID and GC/MS profiling of the ethanolic fruit extract of *Sterculia lanceolata* Cav. revealed a chemically diverse composition containing phenolic compounds, alkaloids, flavonoid-related metabolites, heterocyclic nitrogen compounds, esters, steroid-related constituents, and aromatic derivatives (Table 2). In total, more than 70 constituents were tentatively identified through comparison of retention indices and mass spectra with NIST library databases.

Table 2 Major compounds identified in the ethanolic extract of *Sterculia lanceolata* Cav. fruits by GC/MS analysis

No.	RT	Compound	Formula	Area (%)	Chemical Group
1	7.4632	Oxathiazepine derivative	$C_{14}H_{20}N_2O_4S$	2.052	Nitrogen heterocycle
2	16.3991	Naproxen tetradecyl ester	$C_{28}H_{42}O_3$	1.175	Fatty acid ester
3	27.3856	Acetic acid ester derivative	$C_{26}H_{43}ClO_3$	1.107	Ester compound
4	42.3361	Fluorinated phenolic compound	$C_{12}H_5F_{13}O_3$	1.380	Phenolic derivative
5	49.3922	Heptafluorobutyramide derivative	$C_{16}H_{10}F_7NO_2$	1.103	Aromatic amide
6	49.4520	Benzimidazole derivative	$C_{21}H_{16}N_2O_2$	1.462	Alkaloid-like compound
7	58.0492	Isopilocarpine	$C_{11}H_{16}N_2O_2$	1.365	Alkaloid
8	58.2232	Bis(p-hydroxyphenyl) derivative	$C_{24}H_{36}O_2Si_2$	3.741	Phenolic compound
9	47.1638	Coumarin derivative	$C_{21}H_{14}O_6$	0.655	Coumarin
10	34.4783	Chromone derivative	$C_{20}H_{18}O_7$	0.441	Flavonoid-related
11	24.7610	19-Norcholesta derivative	$C_{26}H_{38}O$	0.524	Steroid-related
12	21.8237	Quinazolinone derivative	$C_{14}H_{10}N_2O$	0.633	Alkaloid
13	36.3215	Pyrazine derivative	$C_{28}H_{18}F_2N_2$	0.898	Heterocyclic compound
14	41.2682	Pyridine derivative	$C_{19}H_{17}N$	0.525	Nitrogen compound
15	15.2377	Chrysophanol derivative	$C_{21}H_{26}O_4Si_2$	0.424	Anthraquinone

Among the detected compounds, phenolic-related constituents represented one of the dominant groups. The compound 4-methyl-2,4-bis(p-hydroxyphenyl)pent-1-ene derivative exhibited the highest relative peak area (3.741%), suggesting that phenolic metabolites may constitute an important fraction of the extract. Phenolic compounds are widely recognized for their antioxidant potential due to their ability to donate hydrogen atoms

and stabilize free radicals [9, 10]. Several nitrogen-containing heterocyclic compounds were also identified, including quinazolinone, benzimidazole, pyridine, pyrazine, and oxathiazepine derivatives. The oxathiazepine-related compound showed a relatively high abundance (2.052%), indicating that nitrogen-containing metabolites may contribute significantly to the biological activity of the extract. Such compounds have previously been associated with antimicrobial, anti-inflammatory, and antioxidant activities [11]. Flavonoid- and chromone-related metabolites were likewise detected, including chromone and coumarin derivatives. These compounds are known to possess strong radical scavenging and cytoprotective activities in medicinal plants [12]. Additionally, chrysophanol-related anthraquinone derivatives identified in the extract may contribute to antimicrobial and antioxidant effects [13]. The presence of alkaloid-related compounds such as isopilocarpine and benzimidazole derivatives further supports the medicinal potential of the extract. Alkaloids are recognized as important bioactive metabolites exhibiting diverse pharmacological properties including antioxidant and antimicrobial activities [15]. Steroid-like constituents and fatty acid esters were also observed in smaller quantities. These compounds may contribute to membrane stabilization and anti-inflammatory activities [15]. Moreover, numerous trimethylsilyl and silane derivatives detected in the chromatogram are commonly produced during derivatization in GC/MS analysis and indicate the occurrence of polar phytochemicals such as phenolics and organic acids [16].

Overall, the GC/MS profile demonstrated that the ethanolic extract of *Sterculia lanceolata* Cav. fruits contains multiple classes of bioactive phytochemicals that may collectively contribute to its antioxidant and pharmacological properties.

3.3. Evaluation of Antioxidant Activity

The antioxidant activity of the ethanolic extract obtained from the fruits of *Sterculia lanceolata* Cav. was determined using the DPPH free radical scavenging assay. The results demonstrated that the radical scavenging activity increased gradually with increasing extract concentration, indicating a concentration-dependent antioxidant effect (Figure 1). At lower concentrations, the extract exhibited moderate inhibitory activity against DPPH radicals, whereas stronger scavenging effects were observed at higher concentrations, although the activity remained lower than that of the standard antioxidant vitamin C.

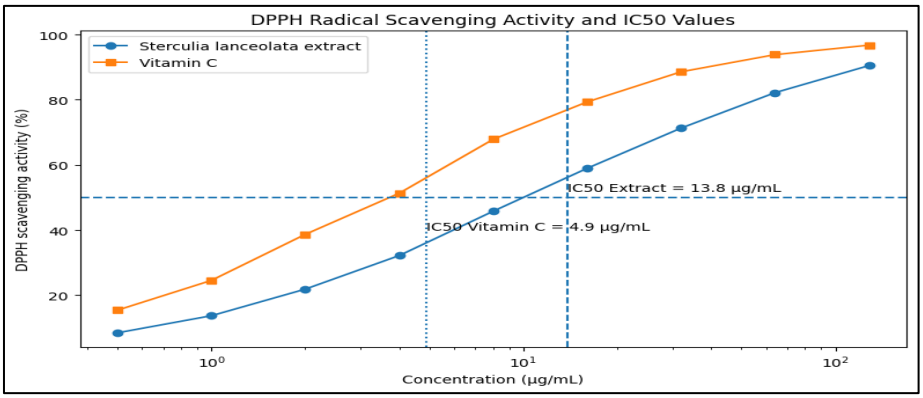

Figure 1 Relationship between extract concentration and DPPH radical scavenging activity (%) of *Sterculia lanceolata* Cav. fruit extract and vitamin C

The ethanolic fruit extract of *Sterculia lanceolata* Cav. exhibited considerable antioxidant potential, suggesting the presence of bioactive metabolites capable of neutralizing free radicals. Previous phytochemical and antioxidant investigations on several *Sterculia* species have similarly reported significant antioxidant activity associated with phenolic compounds, flavonoids, tannins, and related secondary metabolites [17, 3]. These compounds are known to stabilize DPPH radicals through hydrogen atom transfer or electron donation mechanisms, thereby reducing oxidative stress. The antioxidant activity observed in the present study may be associated with the phytochemical constituents identified during qualitative screening and GC/MS analysis, particularly phenolic compounds, flavonoid-related metabolites, alkaloids, coumarin derivatives, and aromatic compounds. Phenolics and flavonoids are widely recognized as effective radical scavengers because their hydroxyl groups can donate protons to reactive oxygen species and terminate radical chain reactions [9,12]. In addition, alkaloids and heterocyclic nitrogen compounds may also contribute to antioxidant and cytoprotective activities [14]. Previous studies on related species such as *Sterculia quadrifida*, *Sterculia rubiginosa*, and *Sterculia foetida* also demonstrated that ethanolic or methanolic extracts rich in phenolic and flavonoid constituents possessed substantial antioxidant capacity [2,3,15]. Therefore, the antioxidant activity detected in the present extract is likely the result of synergistic interactions among multiple classes of secondary metabolites rather than the effect of a single compound.

Although vitamin C exhibited stronger antioxidant efficiency than the ethanolic extract, the fruits of *Sterculia lanceolata*Cav. still showed promising free radical scavenging activity, supporting their potential as a natural source of antioxidant compounds. Nevertheless, the DPPH assay reflects primarily the hydrogen- or electron-donating ability of the extract. Additional antioxidant assays, including ABTS radical scavenging, FRAP reducing power, lipid peroxidation inhibition, and cellular antioxidant activity assays, are required to further elucidate the antioxidant mechanisms and biological significance of the extract.

4. Conclusion

The present investigation demonstrated that the ethanolic extract obtained from the fruits of *Sterculia lanceolata* Cav. contains a variety of biologically important secondary metabolites, including flavonoids, tannins, alkaloids, and saponins. GC/FID and GC/MS analyses revealed a chemically diverse profile with more than 70 identified constituents belonging to different classes such as phenolic compounds, heterocyclic nitrogen compounds, alkaloid-related metabolites, flavonoid-related compounds, esters, and steroid-like derivatives. Several detected compounds, particularly phenolic and flavonoid-related constituents, are known for their antioxidant and pharmacological activities. In addition, the ethanolic fruit extract exhibited noticeable DPPH radical scavenging activity in a concentration-dependent manner, indicating promising antioxidant potential. The observed antioxidant capacity may be associated with the synergistic effects of phenolics, flavonoids, alkaloids, coumarin derivatives, and other bioactive compounds identified in the extract. Overall, the findings suggest that *Sterculia lanceolata* fruits may represent a valuable natural source of antioxidant phytochemicals with potential applications in pharmaceutical, nutraceutical, and functional food industries. Further studies involving quantitative phytochemical analysis, isolation of active constituents, and additional biological evaluations are recommended to clarify the therapeutic potential of this species.

Compliance with ethical standards

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Disclosure of conflict of interest

All the authors hereby declare that no conflicts of interest exist related to this article.

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