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Research article

Effect of brewing conditions of herbal teas from flower and leaf extracts of *Sesbania javanica* Miq. on total phenolic content, vitamin C content and antioxidant activity

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Abstract

Importance of the work: Brewing conditions can reveal major factors for improvement of the components and antioxidant activity of herbal tea**.**

Objectives: To determine the effect of brewing conditions of herbal tea from *Sesbania javanica* Miq**.** flowers and leaves on antioxidant properties, vitamin C content and total phenolic content (TPC) and to identify phytochemicals.

Materials and Methods: The TPC, vitamin C content and antioxidant activity were determined using methods based on Folin-Ciocalteu's phenol reagent, radical scavenging and meta-phosphoric acid, respectively. Chemical components were detected using gas chromatography-mass spectrometry.

Results: The flower water extract produced the highest TPC (70.55 ±1 4.71 µg gallic acid/mg extract) and antioxidant activity ($1/EC_{50}$ = 0.0294 ± 0.0093), while the leaf water extract had the highest vitamin C content (14.22 ± 4.13 µg vitamin C/mg extarct). Flower- and leaf-based teas differed significantly ($p < 0.05$) in TPC, antioxidant activity and vitamin C content. Optimal brewing conditions were flower tea at 70°C for the highest TPC for 10 min (46.73 ± 1.00 µg gallic acid/ mg dried weight) and at 80 °C for 6 min for the highest antioxidant activity ($1/EC_{50}$ = 0.04±0.01), while leaf tea at 90°C for 6 min produced the highest vitamin C content (190.15 ± 4.93 µg vitamin C/mg dried weight). Temperature was weakly negatively associated with TPC (β = -0.44, $p < 0.05$). GC–MS analysis of the flower and leaf ethanol extracts identified several volatile constituents, including 3-methylbutanal, 2-furanmethanol, cyclohexanol, dodecanoic acid, and hexadecanoic acid ethyl ester, while the leaf part contained 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one and dodecanoic acid.

Main finding: The bioactive compounds, vitamin C content and antioxidant potential in herbal tea brewed from *S. javanica* flowers and leaves could be favorable for people wishing to follow a healthy lifestyle.

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Introduction

Currently, a considerable proportion of the global population can be described as an aging society, providing a wake-up call for the adult working population to become more health-conscious through exercise, eating clean foods and managing emotions, which may enhance quality of life in older age (Yen et al., 2022). However, premature aging can occur from several risk factors such as environmental pollutants and negative lifestyle factors such as junk food consumption, stress and insufficient physical activity (Jinesh et al., 2025). Exposure to these risk factors can lead to free radical production that causes oxidative stress, cell and tissue destruction, as well as causing biomolecule defects (DNA mutation and protein dysfunction), which increase early aging and the incidence of non-communicable diseases such as cardiovascular disease, stroke, type 2 diabetes and cancer (Chandimali et al., 2025). Therefore, inhibition of oxidants is one major anti-aging method. Natural antioxidants are commonly in plants as vitamins E and C and phenolic compounds (Traber et al., 2011; Lourenço et al., 2019). Vitamin C is an electron donor compound found in most fruits, which can act as a soluble antioxidant by scavenging radicals (Padayatty et al., 2003). Phenolic compounds are phytochemicals with pharmaceutical activities found in fruits and vegetables. It has been reported that phenolic compounds (ferulic acid, gallic acid, photocatechuic acid) from plants can act as antioxidants by different mechanisms such as hydrogen atom transfer, single-electron transfer, sequential proton loss electron transfer and metal chelation (Kumar and Goel, 2019; Zeb, 2020).

Therefore, the development of functional foods from natural sources has become increasingly popular. Functional foods are foods that provide nutritional value (high vitamins, minerals and phytochemicals) that are beneficial to human health. Many edible plants are used widely in the production of food items with high functional value due to being safe, environmental-friendly and low cost. For example, some herbal teas (*Cymbopogon citratus* leaves, *Foeniculum vulgare* seeds and *Murraya koenigii* leaves) have high functional value due to their antimicrobial, antioxidant and anti-obesity properties due to the various functional groups in the herbal tea (Abdullah et al., 2023). Generally, herbal teas have been used traditionally in folk medicine have been developed continuously by researchers as a functional food due to their pharmacological potential and active constituents (Liu et al., 2023).

The current study focused on *Sesbania javanica* Miq., a native edible plant found widely in Thailand, for development as a functional food for further use by individuals, households and communities, being consumed often in a meat dish and dessert. Plants in the *Sesbania* genus contain diverse active chemicals (quercetin, kaempferol, sesbagrandiforian A and B), with anticancer, antioxidant and anti-proliferative potential (Mokhtar et al., 2025). It has been reported that products from S. javanica produced several kinds of biological activity, including antioxidant and anti-glucosidase activities (Thummajitsakul et al., 2022). In addition, the extract from flowers of *S. javanica* obtained using dimethyl sulfoxide (DMSO) has antimutagenic activity, due to the presence of quercetin 3-2G-rhamnosylrutinoside (Tangvarasittichai et al., 2005), which is a flavonoid glycoside. Additionally, leaf extracts of *S. javanica* showed wound-healing activity (Herabutya et al., 2024). However, there is little available published information on the health value of drinks made from the leaves and flowers of *S. javanica*, especially regarding identifying chemical components and optimizing the appropriate conditions for herbal tea infusion to improve its beneficial levels of biological activity. Gas chromatography-mass spectrometry (GC-MS) is a powerful tool for the identification of chemical components by combining two techniques (gas chromatography and mass spectrometry) to determine the volatile and semi-volatile components in a sample. GC-MS analysis has been used to identify compounds from the ethanol extract of plants, including a triterpene compound (squalene) and a plasticizer compound (1,2-benzenedicarboxylic acid, mono[2-ethylhexyl] ester) (Ezhilan and Neelamegam, 2012). Similarly, GC-MS has been used to identify bioactive compounds namely benzenepropanoic acid, 3-methoxy-alpha,4-bis (trimethylsilyl)oxy and methyl 3-(4-benzyloxy-3, 5-dimethoxyphenyl)-2-methylpropanoate in ethanol extracts of Ocimum tenuiflorum plants (Rajangam et al., 2024).

Hence, the main objectives of the current study were: to determine the effects of the brewing conditions of the flowers and leaves of *S. javanica* on antioxidant properties, vitamin C content and total phenolic content. The, phytochemicals in the leaves and flowers of *S. javanica* were identified using GC-MS analysis. Quantifying the amounts and efficacy of bioactive compounds, the vitamin C content and antioxidant potential in tea brewed using *S. javanica* flowers and leaves would be useful in improving the availability of suitable functional foods such as herbal tea for people wishing to pursue a healthy lifestyle.

Materials and Methods

Chemicals

2,6-Dichloroindophenol sodium salt, gallic acid and absolute ethanol were purchased from Sigma-Aldrich. 3-Ethylbenzothiazoline-6-sulfonic acid diammonium salt (ABTS) were purchased from Sigma. Potassium persulfate and sodium carbonate were purchased from Ajax Finechem. Folin-Ciocalteu's phenol reagent and meta-phosphoric acid were purchased from Merck.

Sample preparation

Fresh flowers and leaves of *S. javanica* were collected from Ongkharak district in Nakhon-Nayok province, Thailand. In the laboratory, each sample was cleaned with water and dried at 50°C for 72 hr. Then, each dried sample was finely homogenized and kept at 4°C (Thummajitsakul et al., 2022).

Sample extraction

Each dried powder sample was extracted with each solvent type (deionized water or ethanol) in the ratio of 1 g of sample per 25 mL of solvent at 45°C for 48 hr. The solvent of each extract was eliminated at 45°C for 20 min for the ethanol solvent and for 30 min for the deionized water using a rotary evaporator (IKAa RV10; IKA10 digital V), according to Thummajitsakul et al. (2020) and Thummajitsakul et al. (2022). Next, each extract was prepared with a concentration of 0.1 g/mL. The extraction was performed in duplicate and the yield percentage was calculated using Equation 1:

$$\% \text{ Yield} = (\text{Weight of extract} / \text{Weight of dried sample}) \times 100 \quad (1)$$

Herbal tea infusion

Dried flower and leave powders (2 g) were placed in tea bags and then infused with water for different periods (2 min, 6 min or 10 min) and temperatures (70°C, 80°C or 90°C). Each tea infusion was performed in duplicate. The time and temperature infusions were divided into three ordinals; low (-1), medium (0) and high (1), as shown in Table 1 (İlyasoğlu and Arpa, 2017).

Total phenolic content

The total phenolic content (TPC) was determined from the reaction between Folin-Ciocalteu's phenol reagent (1.5 mL) and each extract (300 µL) at room temperature for 5 min and finally reacted with 7.5% w/v sodium carbonate (1.2 mL) at room temperature for 30 min. The TPC was performed using four replicates. The TPC was estimated based on a standard graph generated from gallic acid (0–1 mg/mL). For the aqueous and ethanol extracts, the TPC was expressed as micrograms of gallic acid per milligram of extract, while the TPC of the herbal tea was expressed as micrograms of gallic acid per milligram of dried weight (Thummajitsakul et al., 2020; Thummajitsakul et al., 2022)

Antioxidant activity

The antioxidant activity was determined based on 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radical scavenging assay. First, ABTS radical cations were prepared from 7 mM ABTS solution (10 µL) and 140 mM potassium persulfate (179 µL) in dark conditions at room temperature and left overnight. For each assay, the ABTS radical cation solution was diluted with deionized water until reaching an absorbance of 0.700 ± 0.050 at 734 nm, followed by reacting with each sample (20 µL) in dark conditions at room temperature for 6 min and measuring absorbance at 734 nm. The antioxidant activity was performed using four replicates and the percentage of oxidant inhibition was calculated using Equation 2 (Thummajitsakul et al., 2020; Thummajitsakul et al., 2022):

$$\% \text{ Antioxidant capacity} = [(OD_{ABTS} - OD_{Sample\text{-}ABTS}) / OD_{ABTS}] \times 100 \quad (2)$$

where OD_{ABTS} is the absorbance of the diluted ABTS radical cation solution at 734 nm and $OD_{Sample\text{-}ABTS}$ is the absorbance of the reaction of the diluted ABTS radical cation solution with each sample at 734 nm.

Table 1 Conditions for herbal tea infusion

Number	Time (min) (ordinal)	Temperature (°C)
1	2 (-1)	70 (-1)
2	2 (-1)	80 (0)
3	2 (-1)	90 (1)
4	6 (0)	70 (-1)
5	6 (0)	80 (0)
6	6 (0)	90 (1)
7	10 (1)	70 (-1)
8	10 (1)	80 (0)
9	10 (1)	90 (1)

The antioxidant activity was calculated as the inverse value of an effective concentration of each extract used to achieve a 50% inhibition of oxidants (EC_{50}) and denoted as $1/EC_{50}$.

Vitamin C content

The vtamin C content was assayed based on the reaction between 1% meta-phosphoric acid (2.5 mL) with each sample (2.5 mL) at room temperature for 30 min. After that, each reaction (0.5 mL) was mixed with 70 mg/L of 2,6-dichloroindophenol (0.5 mL) and left in dark conditions for 30 min before determining the absorbance at 520 nm. Ascorbic acid (0–1.5 mg/mL) was used as a positive control to generate a standard curve. The vitamin C content was performed using four replicates. For the aqueous and ethanol extracts, the vitamin C content was expressed as micrograms of vitamin C per milligram of extract, while the vitamin C content of the herbal tea was expressed as micrograms of vitamin C per milligram of dried weight (İlyasoğlu and Arpa, 2017).

Gas chromatography-mass spectrometry

Phytochemicals of the flower and leaf ethanol extracts of *S. javanica* were identified using a GC-MS method. A DB-5MS capillary column (30 m × 0.25 mm × 0.25 µm) and a Shimadzu mass spectrometer (Shimadzu; Kyoto, Japan) were used with set conditions (40°C for 1 min, 40–150°C at 8°C/min, 150–200°C at 15°C/min). The temperature conditions for the injector, transfer and ion source were 250°C, 250°C and 200°C, respectively. The carrier gas (helium) was used at a flow rate of 1 mL/min. Details of the spectrum, name, molecular weight and structure of each phytochemical were aligned with the data of known compounds in the National Institute Standard and Technology (NIST14) database (NIST chemistry webbook, 2025). Compound identification was based on the comparison with retention index (RI) values obtained from the GC-MS analysis, the calculated RI values from standard alkanes from Agilent Technologies (2016) and the RI values from the NIST chemistry webbook (http://webbook.nist.gov).

Each RI was calculated from the alkane standards obtained from Agilent Technologies, Inc. using Equation 3:

$$RI = 100 \times [n + (\log RT_i - \log RT_n) / (\log RT_{n+1} - \log RT_n)] \quad (3)$$

where RI is the retention index of each compound in the current study, RT_n is the retention time (RT) of the previous n-alkane, RT_{n+1} is the RT of the following n-alkane, n is the number of carbon atoms of the n-alkane and i is an index for each compound in the current study.

Statistical analysis

The TPC, antioxidant activity and ascorbic acid content were described as mean ± standard deviation. The study was conducted as a factorial experiment in a completely randomized design (CRD). Data were analyzed using three-way analysis of variance (ANOVA) and mean differences were compared using Fisher's LSD, with significance set at $p < 0.05$. Multiple regression analysis was performed to generate regression coefficients (β) for predicting chemical contents and antioxidant activity from tea infusion time and temperature. All statistical analyses were performed using PSPP version 2.0.0 (Pfaff et al., 2007).

Result and discussion

The extracts and herbal tea from *S. javanica* flowers and leaves all contained varying levels of TPC, antioxidant activity and vitamin C content.

The percentage yields of flower and leaf extracts of *S. javanica* in deionized water and ethanol solvent were used to determine the efficiency of the solvents to extract compounds. Based on the result, the maximum percentage yield was obtained by extracting the leaves and flowers with deionized water (49.2 and 68.0%, respectively), followed by ethanol (37.2 and 57.2%, respectively). Additionally, the flower water extract of *S. javanica* had higher values for the TPC (70.55 ± 14.71 µg gallic acid/mg extract) and antioxidant activity ($1/EC_{50}$ = 0.0294 ± 0.0093) than the leaf extract of *S. javanica*, while the leaf water extract produced the maximum level of vitamin C content (14.22 ± 4.13 µg vitamin C/mg extract), as shown in Table 2. However, differences in total phenolic content, antioxidant activity and vitamin C content were not observed between the leaf and flower extracts of *Sesbania javanica* (Table 3).

Table 2 Total phenolic content (TPC, µg gallic acid equivalents/mg extract), antioxidant activity expressed as 1/EC50 (mL/mg; EC50 in mg/mL), vitamin C content (µg vitamin C /mg extract) and extraction yield (%) of Sesbania javanica leaf and flower extracts prepared using water or ethanol.

Sample	Solvent type	TPC	Antioxidant activity	Vitamin C content	Yield (%)
Leaf	Water	42.16±16.43[b]	0.0282±0.0073	14.22±4.13	49.2
	Ethanol	68.72±36.43[a]	0.0226±0.0071	11.20±1.73	37.2
p value		0.036	0.313	0.141	
Flower	Water	70.55±14.71[a]	0.0294±0.0093	13.61±2.65	68.0
	Ethanol	31.70±5.70[b]	0.0174±0.0036	13.51±2.64	57.2
p value		0.000	0.077	0.953	

Mean ± SD with different lowercase superscripts are significantly different ($p < 0.05$) based on independent sample t test; corresponding *p* values are shown.

Table 3 Comparison of total phenolic content (TPC, µg gallic acid equivalents/mg extract), antioxidant activity expressed as $1/EC_{50}$ (mL/mg; EC_{50} in mg/mL) and vitamin C content (µg vitamin C /mg extract) between leaf and flower extracts of *Sesbania javanica*.

Sample	TPC	Antioxidant activity	Vitamin C content
Leaf	55.44±30.79	0.0254±0.0074	12.41±3.13
Flower	53.28±22.86	0.0234±0.0091	13.55±2.49
p value	0.804	0.640	0.378

Mean ± SD with different lowercase superscripts are significantly different ($p < 0.05$) based on independent sample t test; corresponding *p* values are shown.

Furthermore, there were significant differences in the TPC between the water and ethanol extracts of the *S. javanica* flowers and leaves, indicating that some non-phenolic compounds acted as antioxidants (vitamin C and carotenoids). Another study reported that the flower extract of *S. javanica* had a high total carotenoid content and could improve the color of the egg yolk of laying hens (Kijparkorn et al., 2010). Carotenoids, commonly found as pigments in *S. javanica* flowers, act as antioxidants and are poorly soluble in water but readily soluble in ethanol (Mezzomo and Ferreira, 2016). Specifically, the water extract of the *S. javanica* flowers had a higher TPC than the ethanol extract. However, the ethanol extracts from the *S. javanica* leaves had a greater TPC than the water extract, implying that the flowers of *S. javanica* contained high levels of water-soluble phenolic compounds. Phenolic compounds have different aqueous solubility properties. For example, hydroxybenzoic acids (gallic and salicylic acids) were reported by Mota et al. (2008) to have a higher solubility than phenylpropenoic acids (trans-cinnamic, caffeic and ferulic acids). However, Thummajitsakul et al. (2022) reported that the ethanol extract of *S. javanica* flowers had greater levels of TPC and antioxidant activity than the aqueous extract, suggesting that the biological activity levels of plant extracts may be affected by several factors, including harvest date and plant origin. Several phenolic compounds have had reported biological potential regarding antioxidant and anti-diabetic activity (Zeb, 2020; Praparatana et al., 2022). Phenolic compounds can react with several free radicals as antioxidants due to their hydrogen-bonding ability and aromaticity with other functional groups that can increase the antioxidant properties (Zeb, 2020).

Moreover, there were significant differences in the TPC, antioxidant activity and vitamin C content between the flower and leaf tea samples of *S. javanica* (Table 4), with the TPC (27.13 ± 10.24 µg gallic acid/mg dried weight) and antioxidant activity ($1/EC_{50}$ = 0.03 ± 0.01) of the flower tea samples being greater than those of the leaf tea samples, while there was a higher vitamin C content (91.54 ± 48.02 µg vitamin C/mg dried weight) in the leaf tea samples. Consistently, the maximum level of vitamin C content (14.22 ± 4.13 µg vitamin C/mg extract) was in the leaf water extract (Table 2). Furthermore, there were no significant differences among herbal tea infusion times using *S. javanica* leaves and flowers in terms of TPC and antioxidant activity.

Table 4 Comparison of total phenolic content (TPC, µg gallic acid equivalents/mg dried weight), antioxidant activity expressed as $1/EC_{50}$ (mL/mg; EC_{50} in mg/mL) and vitamin C content (µg vitamin C /g dried weight) of *Sesbania javanica* herbal teas by tea type (leaf vs flower) and infusion conditions (time and temperature).

Factor	TPC	Antioxidant activity	Vitamin C content
Herbal tea type			
Leaf tea	22.69±7.43	0.02±0.01	91.54±48.02
Flower tea	27.13±10.24	0.03±0.01	71.08±37.63
p value	0.009	0.016	0.001
Infusion time			
2	23.66±5.24	0.02±0.01	69.00±31.71[b]
6	25.99±10.31	0.03±0.01	104.03±59.77[a]
10	25.10±11.06	0.03±0.01	77.95±37.42[b]
p value	0.504	0.173	0.001
Infusion temperature			
70°C	31.34±11.28[a]	0.03±0.01[a]	82.66±48.96[ab]
80°C	20.69±5.74[b]	0.03±0.01[a]	71.86±35.09[b]
90°C	22.71±5.56[b]	0.02±0.01[b]	92.20±47.44[a]
p value	0.000	0.017	0.005

Mean ± SD with different lowercase superscripts are significantly different ($p < 0.05$) among levels within each factor.

In contrast, there was a significant difference in vitamin C content, which showed the highest level at 6 min. In addition, the tea infusion at different temperatures resulted in the higest TPC and vitamin C content at 70°C and 90°C, respectively, and significant differences in antioxidant activity, which showed the highest levels at 70°C and 80°C (Table 4).

As shown in Table 4, the TPC and antioxidant activity of the flower tea samples were greater than those of the leaf tea samples, while there was a higher vitamin C content in the leaf tea samples. Considering the different conditions tested using herbal tea infusion, the tea type, brewing time, and temperature did not have significant interaction effect on TPC, but they had a siginifcant interaction effect on antioxidant activity and vitamin C content. The antioxidant activity ($1/EC_{50}$ = 0.04±0.01) was the greatest in the flower tea under brewing conditions of 80°C for 6 min, while vitamin C content (190.15±4.93 µg vitamin C/mg dried weight) was the greatest in the leaf tea under brewing conditions of 90°C for 6 min (Table 5).

Another study on *Garcinia schomburgkiana* leaf tea reported that the most suitable time and temperature for extraction of phenolics and antioxidants were 3 or 5 min at 80°C (Thummajitsakul et al., 2020). In addition, the TPC and the tannin contents and antioxidant activity of young leaf tea from *Crotalaria juncea* were higher than in the tea from flowers using brewing conditions of 5 min for 85–90°C (Punchuklang et al., 2021), while the best conditions for white tea infusion to extract a high content of antioxidant polyphenols were at 98°C for 7 min (Pérez-Burillo et al., 2018). Notably, the highest total polyphenols content from fresh tea shrub leaves were achieved using brewing conditions of 100°C for 10 min, while brewing at 100°C for 5 min produced the highest antioxidant activity (Kowalska et al., 2021). Furthermore, the time and temperature conditions for brewing tea leaves were reported to affect the amount of antioxidant activity (Hajiaghaalipour et al., 2016).

The chemical content of tea depends on many factors, including the planting location, harvest date, tea type and infusion conditions (Kowalska et al., 2021). Notably, vitamin C (ascorbic acid) is a water-soluble compound that plays important roles in antioxidant activity, as well as having therapeutic properties regarding cancer, atherosclerosis, diabetes and neurodegenerative disease (Chambial et al., 2013). Although vitamin C is beneficial for good health, it is destroyed readily by high temperatures (Martinsen et al., 2020). In the current study, the brewing temperature and time affected the vitamin C content and antioxidant activity of the edible flower infusion. In addition, it has been reported that using dried flowers for herbal tea infusion decreases the vitamin C content and antioxidant activity compared to using fresh flowers (Nugroho et al., 2023).

Table 5 Total phenolic content (TPC, µg gallic acid equivalents/mg dried weight), antioxidant activity expressed as 1/EC50 and vitamin C content (µg vitamin C/mg dried weight) of *Sesbania javanica* herbal teas prepared from leaves and flowers and brewed at different infusion temperatures (70–90°C) and times (2–10 min).

Tea type	Temperature	Time	TPC	Antioxidant activity	Vitamin C content
Leaf tea	70ºC	2 min	24.26±5.33	0.02±0.00^{cd}	48.36±8.85^{de}
		6 min	29.00±16.06	0.03±0.02 ^{bc}	167.13±4.45^{ab}
		10 min	25.60±3.13	0.03±0.00^{cd}	100.65±42.80^{cd}
	80ºC	2 min	23.20±8.78	0.02±0.01^{cd}	88.36±41.67^{cde}
		6 min	19.34±2.29	0.03±0.01^{bcd}	76.96±29.18^{cde}
		10 min	13.28±3.73	0.02±0.01^{cd}	60.67±42.00^{de}
	90ºC	2 min	22.09±4.50	0.02±0.01^{cd}	61.27±11.31^{de}
		6 min	22.48±3.59	0.02±0.00^{cd}	190.15±4.93^{a}
		10 min	25.00±2.99	0.03±0.00^{bc}	80.68±32.65^{cde}
Flower tea	70 ºC	2 min	28.24±5.21	0.03±0.01^{bcd}	56.30±13.34^{de}
		6 min	24.92±15.33	0.03±0.01^{bcd}	4.09±2.97^{e}
		10 min	46.73±1.00	0.04±0.00^{bc}	55.69±11.48^{de}
	80ºC	2 min	23.76±1.70	0.03±0.00^{bcd}	62.05±31.56^{de}
		6 min	24.91±3.70	0.04±0.01^{a}	63.71±15.89^{de}
		10 min	19.63±4.21	0.03±0.01^{bcd}	72.91±41.19^{de}
	90ºC	2 min	20.41±2.91	0.02±0.01^{cd}	81.67±40.83^{cde}
		6 min	14.97±12.53	0.03±0.00^{bcd}	128.4±59.06^{bc}
		10 min	20.34±2.57	0.02±0.01^{cd}	71.03±8.32^{de}
p value			0.146	0.000	0.038

Values presented as mean ± SD. Mean ± SD with different lowercase superscripts within each column indicate significant differences ($p < 0.05$) among treatments. The *p* value at the bottom indicates the interaction effect of tea type × infusion time × infusion temperature.

In the current study, based on the results of the regression analysis, the temperature applied during herbal tea infusion could be used to predict the TPC ($p < 0.05$). Notably, there was a negative weak correlation between temperature and the TPC ($\beta = -0.44$, $p < 0.05$), as shown in Table 6, which indicated that increasing the brewing temperature decreased the TPC of the herbal tea from *S. javanica* leaves and flowers, probably due to heating and boiling leading to more degradation of phenolic compounds (Bener et al., 2013). Additionally, fluctuations in phytochemical levels in plants can be affected by various factors such as the type of cooking, the plant used, the environment and post-harvest processing (Turkmen et al., 2005; Wen et al., 2010; Kabtni et al., 2020; Lima et al., 2024). Furthermore, in the current study, the time and temperature applied for herbal tea infusion could predict antioxidant activity ($p < 0.05$). There was a very weak correlation for time and temperature with antioxidant activity ($\beta = 0.06$ and 0.03, respectively, $p < 0.05$), as shown in Table 6, indicating that the antioxidant activity of the herbal tea depended mostly on other factors such as the planting location, harvest date and tea type.

Table 6 Multiple regression coefficients (β) and corresponding *p* values for the effects of infusion time and temperature on total phenolic content (TPC), antioxidant activity, and vitamin C content of *Sesbania javanica* herbal teas.

	Time	Temperature	Constant
TPC			
β	0.18	**-0.44**	58.83
p value	0.563	0.001	0.000
Antioxidant activity			
β	0.06	0.03	4.34
p value	0.028	0.032	0.000
Vitamin C content			
β	0.11	1.31	-22.00
p value	0.945	0.520	0.685

The significant β values are bold.

Tangvarasittichai et al. (2005) reported that the flower extract of *S. javanica* contained flavonoids, such as glycoside or quercetin 3-2^{G}-rhamnosylrutinoside, that have antimutagenic activity. Additionally, leaf extracts of *S. javanica* have been reported to have wound-healing activity (Herabutya et al., 2024). However, published data remains limited regarding the levels of phytochemicals and bioactivity of other plant parts and of their associated herbal tea infusion. The current study applied GC-MS analysis to identify the phytochemicals contained in flower and leaf extracts of S. javanica, including some novel components not yet reported from these plant parts (Table 7). Based on the GC-MS results, of the seven novel compounds in the flower, three (2-furan methanol, dodecanoic acid and hexadecanoic acid, ethyl ester) have been reported to produce levels of antioxidant, antibacterial and anti-apoptotic activities (Kim et al., 2014; Guerrero et al., 2017; Renugadevi et al., 2021). Additionally, the leaf extract produced nine novel compounds, of which two (2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one and dodecanoic acid) have been reported to have biological activity in stimulating autonomic nerve activity, as well as antibacterial, antioxidant and anti-apoptotic activities, as shown in Table 7 (Beppu et al., 2012; Renugadevi et al., 2021).

Based on the findings from the current study, herbal tea from the leaves and flowers of S. javanica contained the measurable levels of TPC, vitamin C and antioxidant activity**.** Thus, applications in food industry scaling for antioxidant benefits could utilize the flower and leaf extracts of *S. javanica* into functional foods to enhance health benefits and extend the product shelf life**.** Natural antioxidants have become important compounds of note because of their many benefits, including in food packaging to protect against product degradation and in encapsulation technology to protect the effectiveness of bioactive compounds. Oxidative stress can lead to food spoilage and chronic diseases, including type 2 diabetes, cardiovascular diseases and cancers (Demirci-Çekiç et al., 2020; Chandimali et al., 2025). Natural antioxidants can contribute to the inhibition of lipid oxidation and microbial proliferation in foods and to limiting inflammation and oxidative stress in the human body (Parveen et al., 2025). Therefore, the development of antioxidant benefits should be further studied**.** Notably efficient extraction methods (ultrasound-assisted extraction, pulsed electric field and enzyme-assisted extraction) could improve the production levels of plant extracts to produce antioxidants with higher yields and better quality for industrial applications (Virot, 2010; Waseem et al., 2023).

Based on the current results, the leaves of *S. javanica* contained more extractable phytochemicals than its flower**.** However, many compounds identified have not yet been investigated for their biological activity. These unknown compounds may be useful for health promotion and disease prevention. Therefore, further study is required regarding their medicinal properties. Nonetheless, the current study confirmed the presence of measurable amounts of TPC, vitamin C and antioxidant activity in herbal tea beverages made infusion using *S. javanica* flowers and leaves with different brewing conditions. The TPC yield was dependent on the brewing conditions, especially the temperature. Hence, the flowers and leaves of *S. javanica* would be suitable as natural ingredients in a tea beverage with health benefits. Further research should evaluate customer satisfaction through surveying the likeability, drinkability and acceptability of the different herbal teas to respond appropriately to the needs of tea customers or individuals interested in a healthy lifestyle.

Table 7 Volatile compounds identified in herbal tea from flowers and leaves of *Sesbania javanica* by GC–MS, showing similarity index, molecular weight (MW), retention indices (RIa, RIb, RIc), retention time, molecular formula, and reported biological activities.

Sample	Similarity (%)	Compound name	MW	RI[a]	Retention time (min)	RI[b]$_{cal}$	RI[c]	Formula	Activity types
Flower	91	3-Methylbutanal	86	643	3.519	500	659	$C_5H_{10}O$	
	94	2-Furanmethanol	98	885	5.255	570	857	$C_5H_6O_2$	Antioxidant activity (Kim et al., 2014)
	92	Cyclohexanol	100	908	5.375	674	-	$C_6H_{12}O$	
	90	2,4-Dihydroxy-2,5-dimethyl-3(2H)-furan-3-one	144	1173	6.194	698	-	$C_6H_8O_4$	
	94	1H-Cyclopropa[a]naphthalene, 1a,2,3,5,6,7,7a, 7b-octahydro-1,1,7,7a-tetramethyl-, [1aR-(1a.alpha.,7.alpha.,7a.alpha.,7b.alpha.)]-	204	1403	12.397	1597	1430	$C_{15}H_{24}$	
	91	Dodecanoic acid	200	1570	16.634	1279	1562	$C_{12}H_{24}O_2$	Antibacterial, antioxidant and anti-apoptotic activity (Renugadevi et al., 2021)
	91	Hexadecanoic acid, ethyl ester	284	1978	18.178	1856	1991	$C_{18}H_{36}O_2$	Antioxidant activity (Guerrero et al., 2017)
Leaf	93	3-Methylbutanal	86	643	3.415	495	659	$C_5H_{10}O$	
	95	Methanamine, N-hydroxy-N-methyl-	61	220	3.587	204	-	C_2H_7NO	
	95	Cyclohexanol	100	908	5.307	672	-	$C_6H_{12}O$	
	93	Butanoic acid, 2-methyl-	102	811	5.680	583	876	$C_5H_{10}O_2$	
	93	Benzeneacetaldehyde	120	1081	6.975	826	1051	C_8H_8O	
	94	2-Pyrrolidinone	85	763	8.290	466	-	C_4H_7NO	
	92	2,3-Dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one	144	1269	8.781	680	-	$C_6H_8O_4$	Stimulating autonomic nerve activities (Beppu et al.,2012)
	93	2(4H)-Benzofuranone, 5,6,7, 7a-tetrahydro-4,4,7a-trimethyl-, (R)-	180	1426	15.256	1115	1495	$C_{11}H_{16}O_2$	
	94	Dodecanoic acid	200	1570	16.464	1271	1567	$C_{12}H_{24}O_2$	Antibacterial, antioxidant and anti-apoptotic activity (Renugadevi et al., 2021)

RI = retention index; RI$_{cal}$ =calculated retention index; RI = retention index from NIST chemistry webbook (http://webbook.nist.gov)

Conclusion

The water and ethanol extracts from *S. javanica* flowers and leaves contained high levels of TPC, vitamin C and antioxidant activity. The brewing conditions (time and temperature) of the herbal tea from *S. javanica* flowers and leaves affected the TPC, vitamin C content and antioxidant activity. Based on the regression analysis, increasing the brewing temperature decreased the TPC of tea from *S. javanica* leaves and flowers. Based on the GC-MS analysis, several volatile constituents/compounds were identified in *S. javanica* flowers and leaves, and some have been reported to have antioxidant, antibacterial and anti-apoptotic activities. This knowledge may contribute to improving herbal tea from *S. javanica* flowers and leaves as a potential functional food to respond to the needs of individuals interested in a healthy lifestyle.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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