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Comparative nutritional composition and LC–MS metabolite profiles of two ethno-wild edible flowers, *Pontederia crassipes* Mart. and *Pontederia hastata* L, from Northeast India

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Abstract

Edible flowers contain several phytochemicals including flavonoids, phenolics and anthocyanins. The inflorescences of *Pontederia crassipes* Mart. and *Pontederia hastata* L. are traditionally consumed as food by the Bodo community of Assam, Northeast India. This study aimed to evaluate the proximate composition, mineral content, anti-nutritional factors and qualitative phytochemical screening. Quantitative phytochemical profiles (total phenolic content (TPC), total flavonoid content (TFC)) and antioxidant activities (ferric reducing antioxidant power (FRAP), total antioxidant capacity (TAC) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) assays) were evaluated. Metabolite profiles of the inflorescences of *Pontederia crassipes* Mart. and *Pontederia hastata* L. were determined using gas chromatography–mass spectrometry (GC–MS) and liquid chromatography–mass spectrometry (LC–MS). *Pontederia hastata* exhibited higher crude protein (20.70 ± 0.15 g/100 g dry weight (DW)), crude fat (5.56 ± 0.19 g/100 g DW) and calorific value (405.08 ± 0.48 kcal/100 g DW), whereas *P. crassipes* showed higher total carbohydrate content (71.93 ± 0.25 g/100 g DW). Calcium (Ca) was the predominant mineral in both species, with significantly higher levels detected in *P. hastata* (70.66 ± 0.18 mg/100 g DW). Qualitative phytochemical screening showed the presence of phenol, flavonoid, alkaloid, saponin and tannin. In both the species, TPC, TFC and antioxidant activity as assayed by DPPH, FRAP and TAC were found to be highest in the methanolic extracts. The strongest DPPH radical scavenging activity was observed in the methanolic extract of *P. hastata* (IC_{50} = 44.60 ± 0.25 µg/mL). Anti-nutritional compounds like tannic acid, oxalate, alkaloid, saponin and phytic acid were present at low levels in both the species. The GC–MS and LC–MS analyses of the methanolic extracts of both species showed the presence of diverse putatively annotated metabolites such as flavonoids, phenolics, coumarins, peptides, fatty acids and terpenoids. The findings highlight considerable nutritional and phytochemical potential of these underutilised edible inflorescences as locally available food resources and contribute to food security. Further studies are required for tandem mass spectrometry (MS/MS) confirmation, quantitative profiling of putatively annotated metabolites and assessment of biological activity and toxicity for functional food applications.

Keywords: antioxidant activity; inflorescence; gas chromatography–mass spectrometry; liquid chromatography–mass spectrometry; methanolic extract; nutritional; phytochemical

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Introduction

The use of different plant species as food sources is expanding to embrace new nutrient-rich foods with potential health benefits at a lower cost to improve consumer health and significantly contribute to ecological sustainability (1). The use of edible flowers is increasing because of their nutritional value, therapeutic benefits and the presence of various bioactive compounds. Edible flowers enhance the flavour and attractiveness of various products, including salads, pastries and beverages (2). Edible flowers contain diverse phytochemicals such as carotenoids, terpenes, polyphenols and flavonoids, providing various health benefits (3) and have been investigated for various biological activities (4).

The inflorescences of *Pontederia hastata* L. (Bodo name: Ajinai bibar) and *Pontederia crassipes* Mart. (Bodo name: Mwithukha bibar) are consumed as traditional cuisine by the Bodo community of Assam. Both species are often consumed as chutney prepared with fish or dry fish, by stir-frying, or in the traditional dish 'Ondla,' made from rice flour, alkali and meat or fish. Local communities frequently harvest these inflorescences from the wild for consumption or sell them at local markets for small-scale income. These two wild edible flower species belonging to the genus *Pontederia* are often consumed as

traditional food by the Bodo community of Northeast India, but limited scientific information is available on their nutritional composition and phytochemical profile. Phytochemicals, including flavonoids, phenolic compounds, antioxidants and pharmacological activities, has been reported previously in other plant parts such as leaves, roots and petioles of both species (5, 6). However, there are no comparative studies on the nutritional composition, anti-nutritional content, antioxidant activity and GC–MS- and LC–MS-based metabolite profiles of the two edible inflorescences, *P. crassipes* and *P. hastata*. The aim of the study was to compare their proximate composition, mineral content, anti-nutritional content, antioxidant activity and metabolite profiles using GC–MS and LC–MS.

Materials and Methods

Plant collection and sample preparation

The fresh inflorescences of *P. hastata* and *P. crassipes* were collected during July–September 2025 from the areas of Ambagaon (26°44'24" N 92°2'39" E), Barnagaon (26.7525° N 92.0834° E) and Sapkhaiti (26.7495° N, 92.0774° E) in Udalguri District, Assam, Northeast India. The plant species were identified with the help of relevant taxonomic literature and voucher specimens were deposited in the Bodoland University Botanical Herbarium (BUBH), Kokrajhar, Assam, India. The accession numbers assigned were BUBH25000003 to *P. hastata* and BUBH25000004 to *P. crassipes*. The updated nomenclature of the specimens was verified using online databases such as Plants of the World Online and the World Flora Online. *P. crassipes* is the currently accepted name and it was previously known as *Eichhornia crassipes* (Mart.) Solms; it is an invasive species. The collected inflorescences were washed with double-distilled water and dried in the shade for 7–10 days. The dried inflorescences were ground to a coarse powder using an electric grinder and stored in an airtight container at 4 °C for future use.

Proximate composition analysis

Proximate composition, including moisture content, crude ash, crude fat, crude fibre and crude protein, was determined by following the standard methods of the Association of Official Analytical Chemists (AOAC) (7). Moisture content was measured using the hot-air oven drying method at 105 °C, crude ash with a muffle furnace at 550 °C, crude fat with the Soxhlet extraction method using hexane, crude protein using the Kjeldahl method with a nitrogen (N)-to-protein conversion factor of 6.25 and crude fibre with the acid–alkali digestion method.

Total carbohydrate

Total carbohydrate was determined using the formula based on dry weight (DW) (8).

Total carbohydrate (DW) = 100 − Percentage (moisture + crude ash + crude protein + crude fat)

Calorific value

The calorific value was calculated as kcal/100 g by using the formula (9):

Calorific value (kcal/100 g DW) = 4 (protein percentage) + 9 (fat percentage) + 4 (carbohydrate percentage)

Mineral analysis

A 1 g portion of the powdered samples was digested using a mixture of 65 % nitric acid (HNO_3) and 37 % hydrochloric acid (HCl) prepared in a 1 : 3 ratio. The mixture was then heated in a boiling water bath at 95 °C for 4–5 hr, until it was completely digested and became colourless. After digestion, the samples were filtered using Whatman No. 42 filter paper. The final filtrate was made up to a volume of 50 mL with deionised water. Mineral content was quantified using an atomic absorption spectrophotometer (Thermo Fisher Scientific ICE3300) (10).

Determination of anti-nutritional content

Oxalate content

A 2 g portion of the powdered samples was placed in a flask containing 75 mL of 3 M sulphuric acid (H_2SO_4). The mixture was agitated for 1 hr with a magnetic stirrer (11). After filtering, 5 mL of the filtrate was titrated against a 0.05 M potassium permanganate ($KMnO_4$) solution until the appearance of a reddish-brown colour. One mL of 0.05 mol/L $KMnO_4$ contains 2.2 mg of oxalate. The oxalate content in the samples was calculated as follows:

Oxalate content (mg/100 g) = $T \times 2.2 \times (V_{Total} \times V_{Aliquot}) \times 100/W$

where T = titrate value (volume of $KMnO_4$ in mL), V_{Total} = total volume of the extract, $V_{Aliquot}$ = volume of the filtrate used for titration, W = weight of the sample.

Phytic acid content

The phytic acid content was calculated by the titrimetric method (12). A 2 g portion of the powdered samples was macerated in 100 mL of 2 % HCl for 3 hr and filtered. A 25 mL portion of the filtrate was placed in a flask containing 5 mL of 0.3 % $[NH_4]$ + $[SCN]^-$. The solution was titrated against a standard ferric chloride ($FeCl_3$) solution containing 0.00195 g of iron (Fe) per milliltre. The phytic acid content was determined using the following formula:

$$\text{Phytic acid} = y \times 1.19 \times 100 \quad (4)$$

where y = titre value × 0.00195 g

Estimated total alkaloid content

For the estimation of alkaloid content, 5 g of the powdered samples were macerated in 200 mL of a 10 % acetic acid solution for 4 hr and filtered. The filtrate was then precipitated by adding drops of concentrated ammonium hydroxide (NH_4OH) (28 %), followed by its evaporation to a quarter of its initial volume by heating. The precipitate was washed with 20 mL of 1 % ammonia solution and then dried at 80 °C (13). Alkaloid content was determined using the following formula:

Alkaloids = (Final weight of the residue/weight of sample) × 100

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Estimated total saponin content

A 5 g portion of the powdered samples was extracted with 100 mL of 20 % aqueous ethanol in a water bath at 55 °C for 4 hr and filtered; the process was repeated using the residue. After combining and concentrating the two extracts in a water bath at 90 °C, purification was carried out in a separating funnel using 60 mL of n-butanol and 20 mL of diethyl ether. The butanol extract was washed twice with 5 % sodium chloride (NaCl). After discarding the NaCl layer, the remaining solution was boiled for 30 min in a water bath and then dried in an oven (14). The saponin content was determined using the following formula:

Saponin = (weight of residue / weight of sample) × 100

Tannin content

To a 5 g portion of the powdered sample, 500 mL of double-distilled water was added. The mixture was then gently heated on a hot plate at 50 °C for 1 hr and filtered using Whatman filter paper No. 42. The filtrate was diluted with 50 mL of double-distilled water. A 1 mL portion of the extract (aliquot volume) was pipetted into a conical flask and 0.5 mL of Folin–Denis reagent, 1 mL of saturated sodium carbonate (Na_2CO_3) solution and 8 mL of double-distilled water were added. The final mixture was vortexed for 5 min, allowed to stand for 30 min in a water bath at 25 °C and then analysed at 725 nm with a UV–visible spectrophotometer (UV-1900i, Shimadzu). Tannic acid (0.2–1.0 mg/mL) was used as the standard. To each concentration, 0.5 mL of Folin–Denis reagent, 1 mL of saturated Na_2CO_3 solution and 8 mL of distilled water were added. The mixture was allowed to stand for 30 min in a water bath at 25 °C (15).

Preparation of plant extracts

A 20 g portion of the powdered samples were weighed and the samples were extracted using three different solvents: methanol, hexane and Milli-Q water aqueous extract. The samples were extracted using a Soxhlet apparatus for 6–8 hr. The excess solvents were removed with a rotary evaporator (Ikon TK-154).

Phytochemical screening

Qualitative phytochemical screening of methanolic, aqueous and hexane extracts of the samples was performed to detect the presence of alkaloids (Wagner's test), anthocyanins (ammoniacal test), flavonoids (lead acetate test), phenols (ferric chloride test), saponins (frothing test) and tannins (Braymer's test) (13, 16).

Determination of total phenolic content

The TPC in the extracts was measured using Folin–Ciocalteu reagent, with gallic acid as the standard. A 50 µL portion of the extracts were diluted in 1.8 mL of distilled water. A 1 mL portion of a 10 % Na_2CO_3 solution was added and mixed gently. After 2–3 min, 150 µL of the Folin–Ciocalteu reagent was added to the mixture, which was then allowed to stand at room temperature for 10–20 min. The absorbance was measured at 765 nm using a UV–Visible spectrophotometer (UV-1900i, Shimadzu). The phenolic content in the extracts was calculated as milligrams of gallic acid equivalent per gram of dry weight (mg GAE/g DW), using the equation derived from the gallic acid standard curve (17).

Determination of total flavonoid content

The TFC was determined with an aluminium chloride ($AlCl_3$) colourimetric assay using quercetin as the standard (18). A 1 mL portion of 2 % $AlCl_3$ in methanol was added to 50 µL of an extract (5 mg/mL in 5 % dimethyl sulfoxide (DMSO)) and the volume was made up to 1.95 mL with distilled water. The resultant mixture was allowed to incubate at room temperature for 10–12 min. The absorbance was subsequently measured at 415 nm using a UV–visible spectrophotometer (UV–1900i, Shimadzu). The concentration of flavonoids was calculated as quercetin equivalents (QE) per gram of DW, using the standard curve generated from quercetin.

Determination of the total antioxidant capacity

The total antioxidant capacity (TAC) was determined by the phosphomolybdate assay using ascorbic acid as the standard (19). A 1 mL portion of the reagent solution, consisting of 0.6 M H_2SO_4, 28 mM trisodium phosphate (Na_3PO_4) and 4 mM ammonium heptamolybdate [$(NH_4)_6Mo_7O_{24}$], was mixed with 0.1 mL of the aliquot solution. The volume of the mixture was made up to 3 mL with double-distilled water. The solution was incubated at 95 °C in a water bath for 90 min. Absorbance was recorded at 765 nm using a UV–visible spectrophotometer. The TAC was calculated using the standard graph of ascorbic acid and the results were expressed in milligrams of ascorbic acid equivalent (AAE) per gram of DW).

Determination of ferric-reducing antioxidant power

The ferric reducing power of the extracts was estimated by the ferric-reducing antioxidant power (FRAP) assay using ascorbic acid as a reference standard (20). A mixture of 1 mL of 1 % potassium ferricyanide ($K_3[Fe(CN)_6]$) and 1 mL of a 0.2 M phosphate buffer (pH 6.6) was prepared with 10–50 µL of the extracts. This mixture was incubated in a water bath at 50 °C for 30 min. A 1 mL portion of 10 % trichloroacetic acid (TCA) was added and the mixture was centrifuged for 10 min at 3000 rpm. A 1 mL portion of the supernatant was combined with 0.5 mL of 0.1 % $FeCl_3$ and 1.5 mL of double-distilled water. The absorbance was recorded at 700 nm using a UV–visible spectrophotometer.

Determination of DPPH radical scavenging activity

The free radical scavenging activity of the extracts was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, using ascorbic acid as the standard (21). Absorbance was measured at 517 nm using a UV–visible spectrophotometer. The inhibitory activity against DPPH is expressed as half-maximal inhibitory concentration (IC_{50}) values. To calculate the DPPH scavenging effect, the following equation was used:

$$\text{DPPH scavenging effect (\%)} = (A_0 - A_1)/A_0 \times 100 \quad (7)$$

where A_0 represents the absorbance of the control and A_1 is the absorbance of the reaction mixture.

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Gas chromatography–mass spectrometry analysis

A 10 g portion of the powdered samples was weighed and continuously extracted for about 6–8 hr using an high-performance liquid chromatography (HPLC)-grade methanol solvent. The methanolic extract was analysed using GC–MS (PerkinElmer Clarus680 GC/600C MS) equipped with an autosampler Turbo Mass Ver. 6.1.2. and an Elite-5MS capillary column (30 m × 0.25 mm × 0.25 µm film thickness) for 40 min. Helium (He) gas was used at a constant flow rate of 1.0 mL/min. A 1 µL portion of the aliquot was injected in split mode (split ratio 10 : 1) at 250 °C. After being held for 2 min at 60 °C, the oven temperature was increased to 280 °C and then maintained at that temperature for 10 min. Mass spectra were recorded at 70 eV in electron ionisation (EI) mode at 230 °C in the mass range of m/z 40–600. Putative identification of compounds was performed by comparing the mass spectra with the National Institute of Standards and Technology-2014 (NIST) library (22). Only metabolites showing high peaks and similar mass spectra were considered. Background noise and probable synthetic artefacts were excluded. No reference standards or MS/MS fragmentation analyses were used for confirmation.

Liquid chromatography–mass spectrometry analysis

A 1 g portion of the powdered samples was weighed and then sonicated for 30 min using 4 mL of methanol and centrifuged for 15 min at 4700 rpm. The supernatant was collected in a 10 mL volumetric flask. The procedure was repeated twice, each time using 3 mL of methanol and the extracts were filtered through 0.45 µm polytetrafluoroethylene (PTFE) filters (23). The samples were analysed using LC–MS (Waters Alliance 2695), equipped with an AccuCore C18 column (150 × 4.6 mm, 2.6 µm) at 40 °C, connected to a Waters 2998 photodiode array (PDA) detector and an electrospray ionisation mass spectrometry (ESI-MS) detector operated using Mass Lynx 4.1. Acetonitrile (Solvent B) and 5 mM acetic acid in 5 % acetonitrile/water (Solvent D) were used as the mobile phase. A 10 µL portion was injected at a 1.0 mL/min flow rate, with a 40 min run time. The gradient programme was initiated with 5 % B and 95 % D for 1 min; B was increased linearly to 30 % by 10 min, then to 60 % by 14 min and held for 2 min. From 16–24 min, it was further increased to 80 %, then held for 32 min and the composition was returned to 5 % B by 35 min, with the programme continuing until 40 min. PDA detection was carried out at 200–450 nm in both positive and negative ESI modes within the m/z range of 100–750, with capillary voltages of +3.5 kV and −2.5 kV at 120 °C and 350 °C, using N as the cone and desolvation gas. Untargeted metabolite profiling was performed using MS1 accurate mass matching and detailed searches of online databases, including Kyoto Encyclopedia of Genes and Genomes (KEGG), MassBank of North America (MoNA) and publicly accessible chemical database (PubChem). The raw data obtained were processed using MZmine 2.53 software. Metabolites were putatively annotated based on retention time (min), m/z, area percentage, molecular formula and chemical class without confirmation against reference standards or through MS/MS fragmentation. Column artefacts and synthetic compounds were excluded.

Statistical analysis

Statistical analysis was performed using R software (version 4.5.2). One-way ANOVA followed by Tukey's honestly significant difference (HSD) test at a significance level of $p < 0.05$ was used to detect significant differences in the proximate composition, mineral content and anti-nutritional content between the two species. Two-way ANOVA with Tukey's HSD test at a significance level of $p < 0.05$ was performed to analyse phytochemical and antioxidant activity. Multivariate (heatmap) analysis was conducted. All analyses were performed using three analytical replicates ($n = 3$) of powdered samples. Results were presented as mean ± standard deviation (SD).

Results

Nutritional analysis

The proximate composition, such as moisture content, crude ash, crude fat, crude fibre, crude protein, total carbohydrate and calorific value, is given in Table 1. Moisture content was higher in *P. crassipes* (84.81 ± 0.13 g/100 g fresh weight (FW)) than in *P. hastata* (78.70 ± 0.18 g/100 g FW). *Pontederia crassipes* showed higher crude ash (8.70 ± 0.19 g/100 g DW), crude fibre (18.81 ± 0.27 g/100 g DW) and total carbohydrate content (71.93 ± 0.25 g/100 g DW) than *P. hastata*. In comparison, *P. hastata* showed higher crude protein (20.70 ± 0.15 g/100 g DW), crude fat (5.56 ± 0.19 g/100 g DW) and calorific value (405.08 ± 0.48 kcal/100 g) than *P. crassipes*.

Table 1. Proximate composition (g/100 g dry weight (DW)) and moisture content (g/100 g fresh weight (FW)) of the inflorescence of *Pontederia crassipes* and *Pontederia hastata*

Proximate composition (g/100 g DW)	*Pontederia crassipes*	*Pontederia hastata*
Moisture content (FW)	84.81 ± 0.13[a]	78.70 ± 0.18[b]
Crude ash	8.70 ± 0.19[a]	5.68 ± 0.13[b]
Crude fat	3.60 ± 0.16[b]	5.56 ± 0.19[a]
Crude fibre	18.81 ± 0.27[a]	12.59 ± 0.23[b]
Crude protein	15.77 ± 0.17[b]	20.70 ± 0.15[a]
Total carbohydrate	71.93 ± 0.25[a]	68.06 ± 0.22[b]
Calorific value	383.20 ± 0.49[b]	405.08 ± 0.48[a]

DW: dry weight; FW: fresh weight.

All the values are given as mean ± SD (n = 3). Moisture content is reported as FW and other proximate contents are on a DW basis. Values within the same row with different superscript letters have a significant difference at $p < 0.05$ according to one-way ANOVA and Tukey's HSD test

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Mineral content

The mineral composition, including Ca, potassium (K), magnesium (Mg), sodium (Na), copper (Cu), Fe, manganese (Mn) and zinc (Zn), of the edible inflorescences *P. crassipes* and *P. hastata* is given in Table 2. All the minerals except Cu showed significant interspecific differences at $p < 0.05$. *Pontederia hastata* showed significantly higher contents of Ca, K and Zn than *P. crassipes*. On the other hand, the contents of Mg, Na, Fe, Mn and Cu were slightly higher in *P. crassipes* than in *P. hastata*. Among all the minerals analysed, Ca was present in the highest amount in both species, at 70.66 ± 0.18[a] mg/100 g DW in *P. hastata* and 46.79 ± 0.11[b] mg/100 g DW in *P. crassipes*.

Table 2. Mineral content (mg/100 g dry weight (DW)) of *Pontederia crassipes* and *Pontederia hastata* inflorescences

Minerals (mg/100 g DW)	*Pontederia crassipes*	*Pontederia hastata*
Ca	46.79 ± 0.11[b]	70.66 ± 0.18[a]
K	30.72 ± 0.13[b]	38.72 ± 0.12[a]
Mg	9.65 ± 0.20[a]	8.51 ± 0.18[b]
Na	15.83 ± 0.17[a]	14.90 ± 0.18[b]
Cu	1.49 ± 0.26[a]	0.79 ± 0.16[a]
Fe	3.74 ± 0.10[a]	2.83 ± 0.19[b]
Mn	3.39 ± 0.22[a]	2.60 ± 0.18[b]
Zn	0.76 ± 0.12[b]	1.66 ± 0.18[a]

DW: dry weight; Ca: calcium; K: potassium; Mg: magnesium; Na: sodium; Cu: copper; Fe: iron; Mn: manganese; Zn: zinc.

All the values are given in mean ± SD (n = 3) in dry weight (DW). Values within the same row with different superscript letters have a significant difference at $p < 0.05$ according to one-way ANOVA and Tukey's HSD test.

Anti-nutritional content

The anti-nutritional content in the inflorescences of *P. crassipes* and *P. hastata* is given in Table 3. Significant differences ($p < 0.05$) were observed between the species. Among the measured anti-nutritional factors, tannin, phytic acid and saponin contents were comparatively higher in *P. hastata*, whereas oxalate and alkaloid contents were higher in *P. crassipes*.

Table 3. Anti-nutritional content (mg/100 g dry weight (DW)) in the *Pontederia crassipes* and *Pontederia hastata* inflorescences

Anti-nutritional factor	*Pontederia crassipes*	*Pontederia hastata*
Alkaloid	1.87 ± 0.10[a]	1.30 ± 0.26[b]
Oxalate	6.37 ± 0.20[a]	4.37 ± 0.18[b]
Phytic acid	1.79 ± 0.19[b]	2.54 ± 0.31[a]
Saponin	0.60 ± 0.21[b]	1.09 ± 0.28[a]
Tannin	6.65 ± 0.22[b]	10.47 ± 0.33[a]

All the values are given in mean ± SD (n = 3) in dry weight (DW). Values within the same row with different superscript letters have a significant difference at $p < 0.05$ according to one-way ANOVA and Tukey's HSD test.

Phytochemical screening

The qualitative phytochemical screening of *P. crassipes* and *P. hastata* showed the presence of alkaloid, flavonoid, phenol and saponin (Table 4). Tannins were detected in all extracts except the hexane extract of *P. crassipes*.

Table 4. Phytochemical screening of *Pontederia crassipes* and *Pontederia hastata* inflorescences

Phytochemicals	Test	*Pontederia crassipes*			*Pontederia hastata*		
		ME	AQE	HE	ME	AQE	HE
Alkaloid	Wagner's test	+	+	+	+	+	+
Flavonoid	Lead acetate test	+	+	+	+	+	+
Phenol	Ferric chloride test	+	+	+	+	+	+
Saponin	Frothing test	+	+	+	+	+	+
Tannin	Braymer's test	+	+	–	+	+	+

"+": present; "–": absent; AQE: aqueous extract; HE: hexane extract; ME: methanol extract.

Total phenolic content

The TPC in the inflorescences of *P. crassipes* and *P. hastata* extracts varied significantly ($p < 0.05$) depending on the solvents (Table 5). The concentrations are given as GAE/g DW using the standard curve for gallic acid ($y = 0.0061x + 0.035$, $R^2 = 0.9981$). Comparatively higher phenolic contents were observed in methanolic extracts than in aqueous and hexane extracts in both species. The methanolic extract exhibited the highest TPC value in both species, 47.38 ± 0.26 mg GAE/g DW in *P. hastata*, followed by 40.82 ± 0.29 mg GAE/g DW in *P. crassipes*. In *P. crassipes*, the aqueous extracts had a moderate phenolic content of 37.21 ± 0.26 mg GAE/g DW and 30.98 ± 0.35 mg GAE/g DW in *P. hastata*. Hexane extracts exhibited the lowest TPC values, 21.48 ± 0.33 mg GAE/g DW in *P. crassipes* and 21.15 ± 0.36 mg GAE/g DW in *P. hastata*, with no significant difference.

Total flavonoid content

The TFC of the inflorescences of *P. crassipes* and *P. hastata* was calculated as quercetin equivalents per gram of dry weight (QE/g DW) using the standard graph of quercetin ($y = 0.009x - 0.046$, $R^2 = 0.9985$) (Table 5). The TFC of *P. crassipes* and *P. hastata* varied significantly ($p < 0.05$) between the three different solvents. Methanolic extracts showed higher levels of flavonoids than aqueous and hexane extracts in both species. The methanolic extract exhibited a higher TFC value in *P. hastata* (38.73 ± 0.38 mg QE/g DW), followed by *P. crassipes* (31.89 ± 0.30 mg QE/g DW). The aqueous extracts had a moderate flavonoid content, with 22.76 ± 0.21 mg QE/g DW in *P. hastata* and 11.76 ± 0.11 mg QE/g DW in *P. crassipes*. The hexane extracts showed the lowest TFC values, 6.47 ± 0.24 mg QE/g DW in *P. crassipes* and 13.91 ± 0.20 mg QE/g DW in *P. hastata*.

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Table 5. Total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), total antioxidant capacity (TAC) and DPPH assay (IC_{50} values) of *Pontederia crassipes* and *Pontederia hastata* inflorescences

Species	Solvent	TPC (mg GAE/g DW)	TFC (mg QE/g DW)	TAC (mg AAE/g DW)	FRAP (mg AAE/g DW)	DPPH IC_{50} (µg/mL)
	ME	40.82 ± 0.29^{b}	31.89 ± 0.30^{b}	24.72 ± 0.18^{b}	12.26 ± 0.21^{a}	52.58 ± 0.29^{e}
Pontederia crassipes	AQE	37.21 ± 0.26^{c}	11.76 ± 0.11^{e}	11.74 ± 0.11^{d}	5.43 ± 0.20^{d}	60.48 ± 0.35^{c}
	HE	21.48 ± 0.15^{e}	6.47 ± 0.24^{f}	6.10 ± 0.15^{e}	4.03 ± 0.21^{e}	104.51 ± 0.24^{a}
	ME	47.38 ± 0.26^{a}	38.73 ± 0.38 ^{a}	37.51 ± 0.11^{a}	8.73 ± 0.22^{b}	44.60 ± 0.25^{f}
Pontederia hastata	AQE	30.98 ± 0.35^{d}	22.76 ± 0.21^{c}	15.67 ± 0.21^{c}	6.66 ± 0.32^{c}	55.69 ± 0.19^{d}
	HE	21.15 ± 0.12^{e}	13.91 ± 0.20^{d}	10.23 ± 0.25^{d}	5.32 ± 0.22^{d}	82.57 ± 0.10^{b}
Standard	Ascorbic acid	–	–	–	–	14.81 ± 0.15

TPC: total phenolic content; TFC: total flavonoid content; FRAP: ferric reducing antioxidant power; TAC: total antioxidant capacity; DPPH: 2,2-diphenyl-1-picrylhydrazyl; IC_{50}: half-maximal inhibitory concentration; ME: methanolic extract; AQE: aqueous extract; HE: hexane extract.

All the values are given in mean ± SD (n = 3). Values with different superscript letters are significantly different ($p < 0.05$) according to the two-way ANOVA and Tukey's HSD test.

Total antioxidant capacity

Total antioxidant capacity varied significantly ($p < 0.05$) among the different extracts. The standard ascorbic acid graph (y = 0.061x − 0.011, R^2 = 0.9981) was used to quantify the TAC expressed as ascorbic acid equivalents per gram of dry weight (AAE/g DW), as shown in Table 5. The highest TAC value, 37.51 ± 0.11 mg AAE/g DW, was observed in the methanolic extract of *P. hastata*, followed by 24.72 ± 0.18 mg AAE/g DW in the methanolic extract of *P. crassipes*. The lowest TAC value was observed in the hexane extract of *P. crassipes* (6.10 ± 0.15 mg AAE/g DW).

Ferric reducing power

The FRAP of the inflorescences (Table 5) was calculated using the equation y = 0.119x − 0.053, R^2 = 0.9978 and expressed as AAE/g DW. The highest FRAP value was observed in the methanolic extracts of *P. crassipes* (12.26 ± 0.21 mg AAE/g DW) and *P. hastata* (8.73 ± 0.22 mg AAE/g DW). The aqueous extracts showed moderate reducing power, with values of 6.66 ± 0.32 mg AAE/g DW in *P. hastata* and 5.43 ± 0.20 mg AAE/g DW in *P. crassipes*. The lowest FRAP values (4.03 ± 0.21 and 5.32 ± 0.22 mg AAE/g DW) were recorded in the hexane extracts of both the species.

DPPH assay

The DPPH scavenging assay of methanol, aqueous and hexane extracts of *P. crassipes* and *P. hastata* is given in Table 5. The scavenging activities of the species, *P. crassipes* and *P. hastata*, showed significant differences among the extracts. The lowest IC_{50} value (44.60 ± 0.25 µg/mL) was observed in the methanolic extract of *P. hastata*, followed by the methanolic extract of *P. crassipes* (52.58 ± 0.29 µg/mL). Moderate antioxidant activity was found in the aqueous extracts, with IC_{50} values of 55.69 ± 0.19 µg/mL in *P. hastata* and 60.48 ± 0.35 µg/mL in *P. crassipes*. The hexane extracts of *P. crassipes* showed the highest IC_{50} values, at 104.51 ± 0.24 µg/mL, with the lowest DPPH radical-scavenging capacity.

Gas chromatography–mass spectrometry analysis

The chromatogram from the GC–MS analysis of *P. crassipes* and *P. hastata* inflorescences is given in Fig. 1. The putatively annotated metabolites of the methanolic extracts of *P. crassipes* and *P. hastata* inflorescences are given in Table 6. The analysis showed a total of five putatively annotated metabolites in *P. crassipes* and four putatively annotated metabolites in *P. hastata*. The putatively annotated metabolites belong to the classes of furan, furanone, lactone, fatty acid methyl ester, lactam, ketone and fatty acids (Fig. 2). The putatively annotated metabolites in *P. crassipes* were methyl linolenate (2.45 %); methyl 8-methylnonanoate (1.42 %); tetrahydrocyclopenta[1,3]dioxin-4-one (0.54 %); 2-furancarboxaldehyde, 5-methyl (0.50 %); and 2,4-dihydroxy-2,5-dimethyl-3(2H)-furan-3-one (0.44 %). The putatively annotated metabolites in P. hastata were cyclohexanone, 2-methyl-5-(1-methylethenyl) (1.01 %); 2-pyrrolidinone, 1-methyl- (0.86 %); 2-cyclopropene-1-carboxylic acid, 1-methyl-, methyl ester (0.55 %); and nonanoic acid (0.34 %).

Table 6. List of putatively annotated metabolites of the methanolic extracts of *Pontederia crassipes* and *Pontederia hastata* inflorescence using gas chromatography–mass spectrometry (GC–MS)

Sl. No.	RT (min)	Peak area (%)	Putatively annotated metabolites	Molecular formula	Molecular weight	Class
			Pontederia crassipes			
1.	15.241	0.50	2-Furancarboxaldehyde, 5-methyl	$C_6H_6O_2$	110	Furan
2.	15.706	0.44	2,4-dihydroxy-2,5-dimethyl-3(2h)-furan-3-one	$C_6H_8O_4$	144	Furanone

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3.	17.062	0.54	Tetrahydrocyclopenta [1,3] dioxin-4-one	$C_7H_{10}O_3$	142	Lactone
4.	34.409	1.42	Methyl 8-methyl-nonanoate	$C_{11}H_{22}O_2$	186	Fatty acid methyl ester
5.	36.825	2.45	Methyl linolenate	$C_{19}H_{32}O_2$	292	Fatty acid methyl ester
			Pontederia hastata			
1	9.205	0.86	2-Pyrrolidinone, 1-methyl	C_5H_9NO	99	Lactam
2	10.177	0.55	2-Cyclopropene-1-carboxylic acid, 1-methyl-, methyl ester	$C_6H_8O_2$	112	Cyclopropene ester
3	12.267	1.01	Cyclohexanone, 2-methyl-5-(1-methylethenyl)	$C_{10}H_{16}O$	152	Ketone
4	31.608	0.34	Nonanoic acid	$C_9H_{18}O_2$	158	Fatty acid

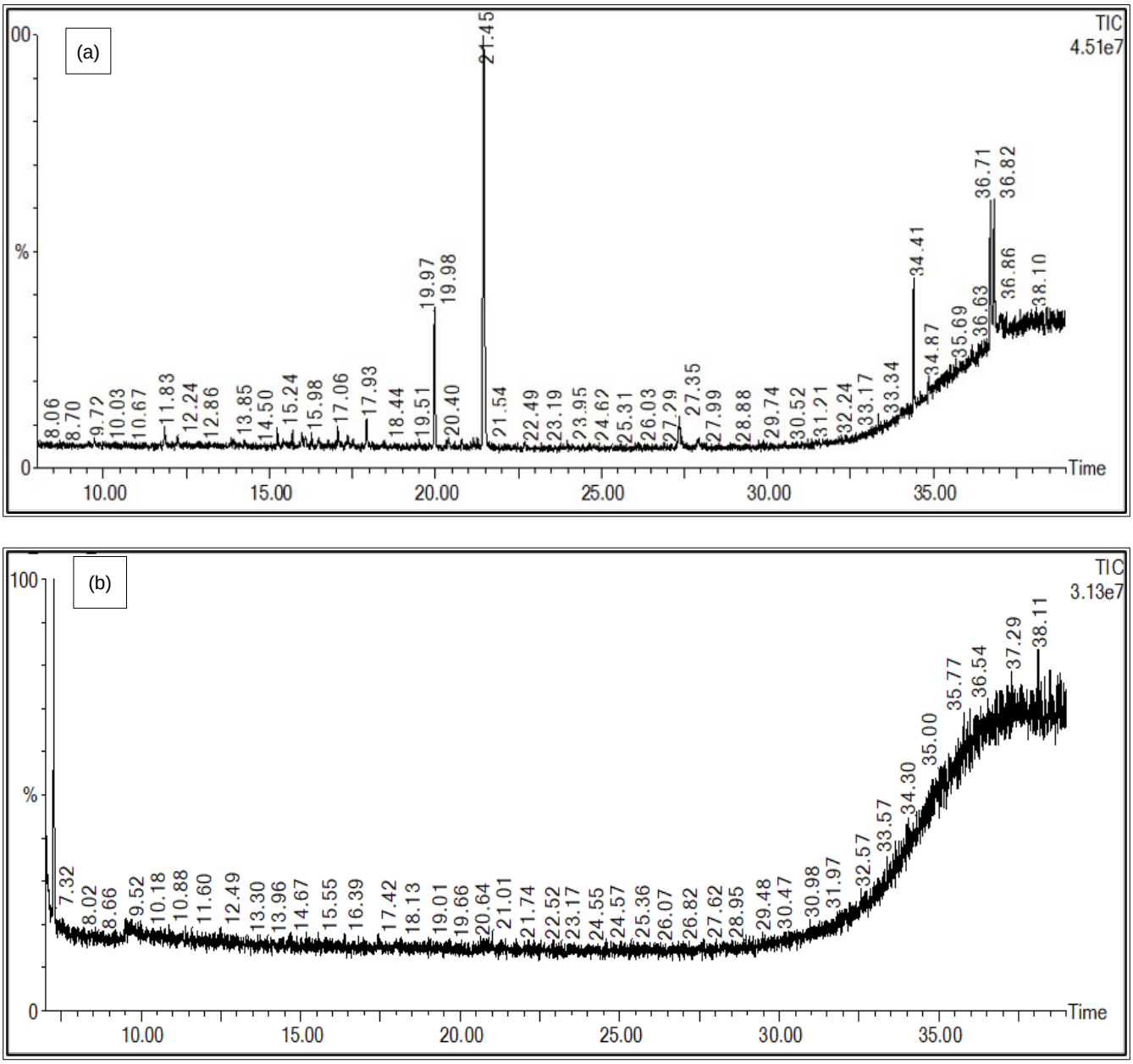
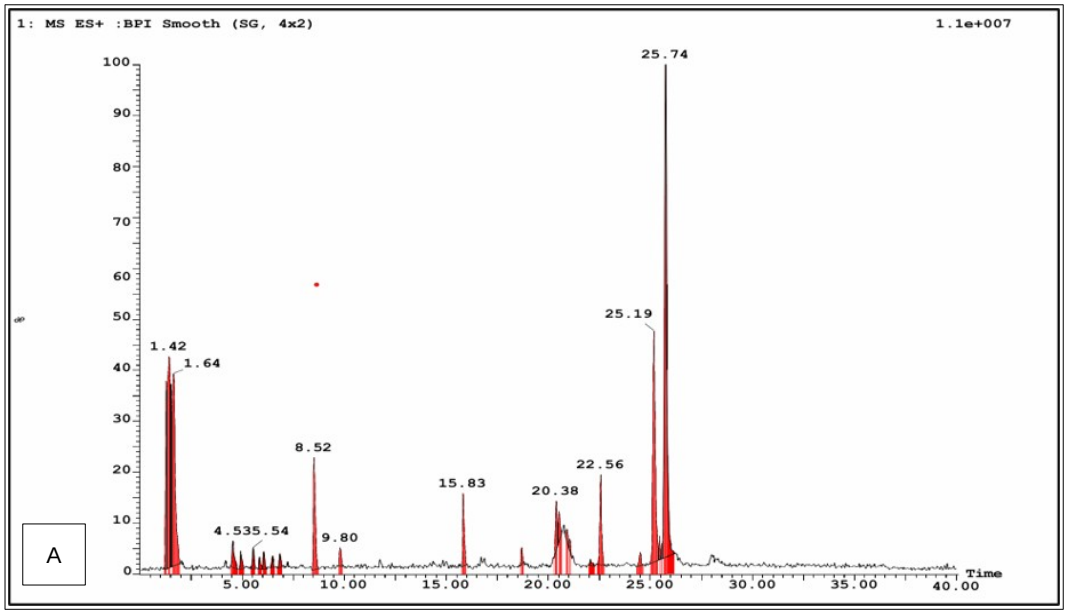
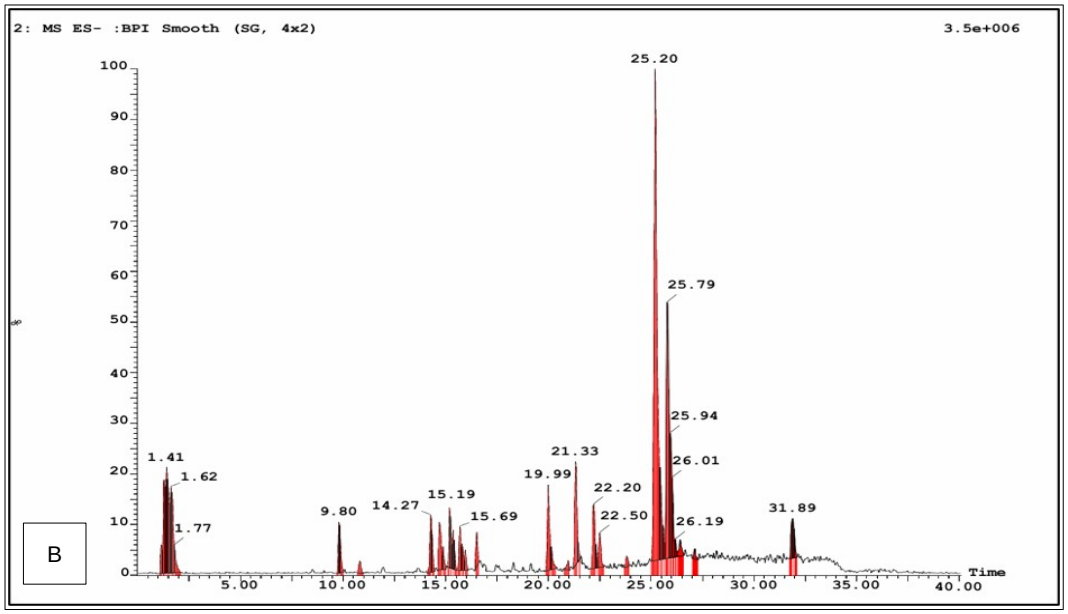
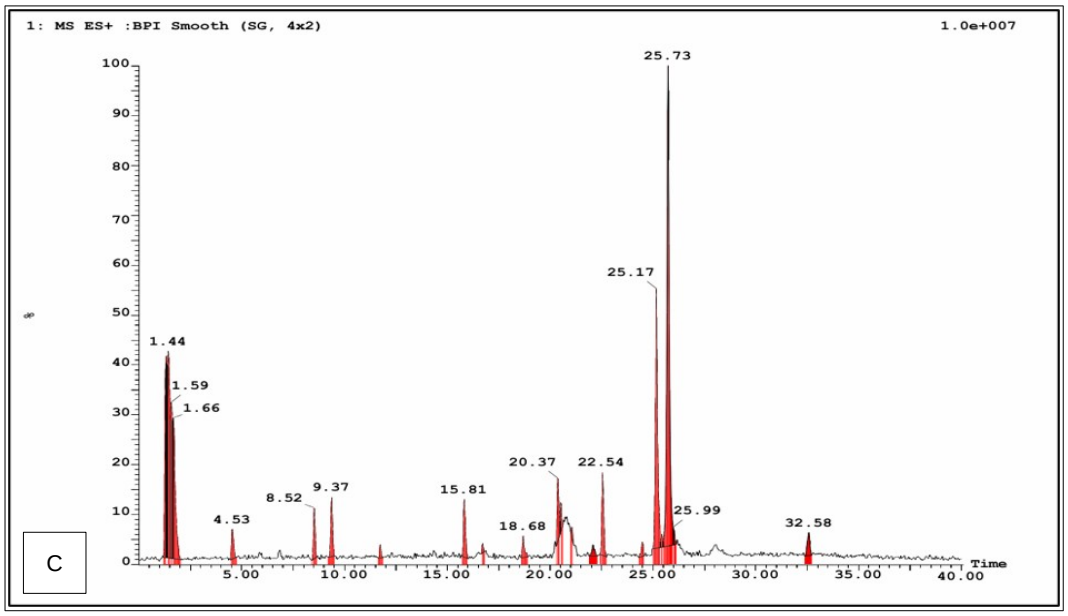


Fig. 1. Gas chromatography–mass spectrometry (GC–MS) total ion chromatograms (TIC) of the methanolic extract of (a) *Pontederia crassipes* and (b) *Pontederia hastata* inflorescences.

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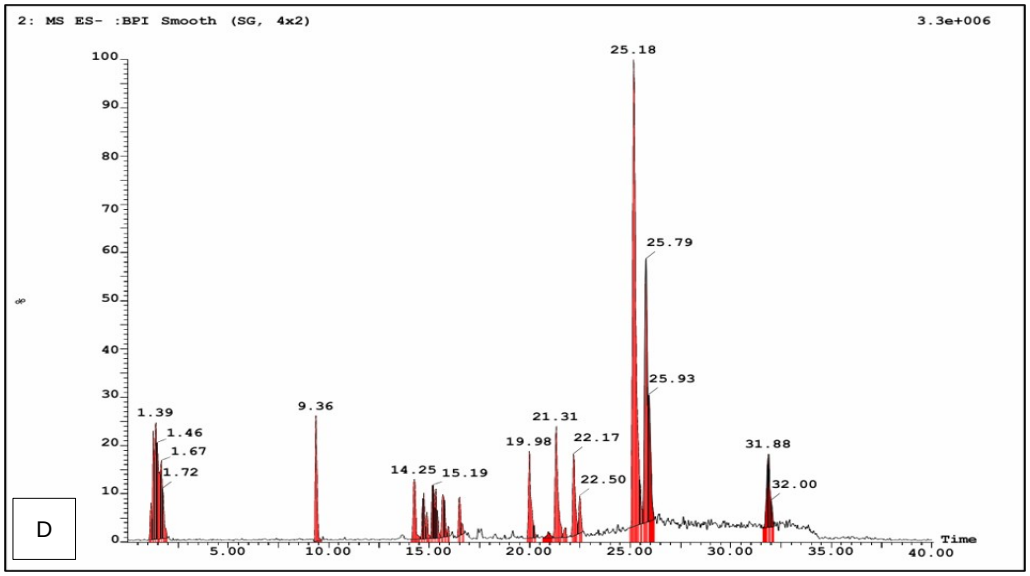


Fig. 2. Liquid chromatography–mass spectrometry (LC-MS) base peak chromatograms of methanolic extract of *Pontederia crassipes* (A) Positive ESI$^+$, (B) Negative ESI$^-$, *Pontederia hastata*, (C) Positive ESI$^+$, (D) Negative ESI$^-$.

Liquid chromatography–mass spectrometry metabolite profiling

Untargeted LC–MS metabolite profiling of the methanolic extracts of both the species revealed 29 putatively annotated metabolites in *P. crassipes* and 26 putatively annotated metabolites in *P. hastata* (Fig. 3). The complete metabolite dataset is provided in the Supplementary Table 1, while only the major putatively annotated metabolites are given in Table 7. The major metabolites include flavonoid and phenolic compounds, followed by terpenoids, glycosides, peptides, amino acid derivatives and lipids. The Venn diagram (Fig. 4A) revealed that five of the putatively annotated metabolites were common to both the species. The common putatively annotated metabolites were formononetin, 1,5-di-O-caffeoylquinic acid, thymol-β-D-glucoside, 4-(3-hydroxybutyl)phenol and dihydrorotenone. In *P. crassipes*, formononetin showed the highest peak area (24.3 %), followed by thymol-β-D-glucopyranoside (20.47 %), dihydrorotenone (10.75 %), L-cysteinylglycine (2.24 %), 1,5-di-O-caffeoylquinic acid (1.84 %) and oleanolic acid (3.81 %). In *P. hastata*, dihydrorotenone showed the highest peak area (12.25 %), followed by thymol-β-D-glucoside (10.95 %) and 1,5-di-O-caffeoylquinic acid (6.21 %). Other putatively annotated metabolites were gamma-carboxyglutamic acid, N-acetyltryptophan, gancaonin A, ferulic acid, skimmin and batatasin III. The heatmap of the top 15 putatively annotated metabolites of *P. crassipes* and *P. hastata* showed different metabolite compositions (Fig. 4B).

Discussion

Nutritional significance

In this study, the proximate analysis showed that *P. hastata* contains comparatively higher crude protein, crude fat and calorific value than *P. crassipes*. Whereas *P. crassipes* exhibited comparatively higher crude ash, crude fibre and carbohydrate content than *P. hastata*. The ash content in the study indicated the accumulation of inorganic mineral constituents such as oxides, phosphates, sulphates and chlorides and essential minerals, including Na, K, Ca, Mg, Fe and Mn. The ash content recorded in both species was within the range of 3.8–22.0 g/100 g DW, as reported in other edible flower species such as *Borago officinalis* L., *Cucurbita pepo* L. and *Centaurea cyanus* L. (24). The crude fat content in both species was also approximately within the same range, i.e., 4.9 g/100 g DW in *B. officinalis* and 5.0 g/100 g DW in *C. pepo* (24). The crude fat content in both species was relatively low and within the range reported for several edible flowers (25). Crude fibre was comparatively higher in *P. crassipes* than in *P. hastata*. A diet with high levels of crude fibre is beneficial for the gut, as it helps with the absorption of trace elements and assists in the excretion of undigested food (26). The protein content of these two species was within the range of 14.5–22.7 g/100 g DW reported for the protein content of other edible flowers such as *B. officinalis*, *C. pepo* and *C. moschata* species (24).

The carbohydrate contents in both species provide a substantial supply of nourishment and help with the digestion and uptake of other nutrients. *Pontederia hastata* contributes about 44.8–58.2 % of the daily requirement of carbohydrate and *P. crassipes* contributes around 35.6–46.3 %. Both *Pontederia* species contain minerals such as Ca, K, Mg, Fe, Zn and Mn, which help balance body fluids, acid–base equilibrium and metabolic functions. These minerals also regulate many metabolic processes and vital enzymatic activities. Compared with previously examined edible flowers, including *Cucurbita moschata* Duchesne, *Dianthus chinensis* L., *Fuchsia regia* (Vand. ex Vell.) Munz and *Viola cornuta* L., both species investigated in the present study had lower mineral content (27).

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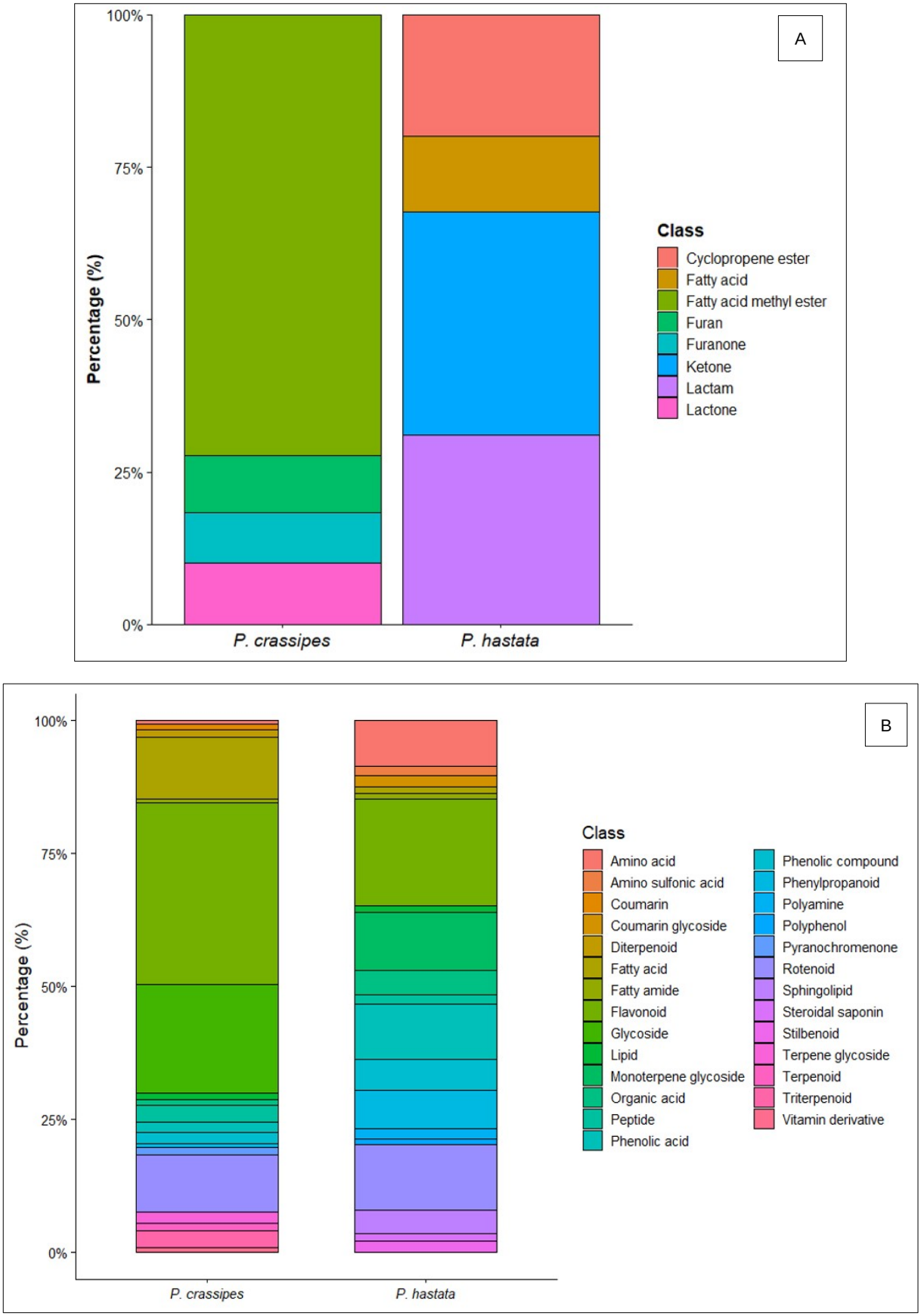


Fig. 3. Comparative stacked bar graph representing the relative distribution of different class of putatively annotated metabolites of *Pontederia crassipes* and *Pontederia hastata*. (A) Gas chromatography–mass spectrometry (GC–MS); (B) Liquid chromatography–mass spectrometry (LC–MS).

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Table 7. Putatively annotated metabolites in the methanolic extract of *Pontederia crassipes* and *Pontederia hastata* inflorescences by untargeted Liquid chromatography–mass spectrometry (LC-MS) analysis

Sl. No.	Putatively annotated metabolite	RT (min)	Experimental (m/z)	Relative peak area (%)	Formula	Class
			Pontederia crassipes			
1.	Formononetin	1.37	269.00	24.3	$C_{16}H_{12}O_4$	Flavonoid
2.	1,5-di-O-caffeoylquinic acid	1.40	515.00	1.84	$C_{25}H_{24}O_{12}$	Phenolic acid
3.	L-Homocystine	1.77	269.07	0.67	$C_8H_{16}N_2O_4S_2$	Amino acid
4.	Baccatin IV	9.82	653.00	0.84	$C_{32}H_{44}O_{14}$	Diterpenoid
5.	Triptophenolide	18.71	311.18	0.58	$C_{20}H_{24}O_3$	Diterpenoid
6.	3-Methyladipic acid	18.73	161.08	0.92	$C_7H_{12}O_4$	Organic acid
7.	Dihydrorotenone	20.42	148.93	10.75	$C_{23}H_{24}O_6$	Rotenoid
8.	4-(3-hydroxybutyl) phenol	20.44	149.09	0.68	$C_{10}H_{14}O_2$	Phenolic compound
9.	(3S)-7-O-methylvestitol	22.56	287.20	1.37	$C_{17}H_{18}O_4$	Flavonoid
10.	Avocadene	22.58	287.26	1.29	$C_{17}H_{34}O_3$	Lipid
11.	Thymol-β-D-glucopyranoside	25.17	311.15	20.47	$C_{16}H_{24}O_6$	Monoterpene glycoside
12.	N-Methylnicotinamide	25.20	135.05	0.99	$C_7H_8N_2O$	Vitamin B3 derivative
13.	Ovalitenin B	25.24	310.86	0.84	$C_{19}H_{18}O_4$	Flavonoid
14.	L-Cysteinylglycine	25.45	179.05	2.24	$C_5H_{10}N_2O_3S$	Peptide
15.	Oleanolic acid	25.71	457.31	1.51	$C_{30}H_{48}O_3$	Triterpenoid
			Pontederia hastata			
1.	2-amino-3-prop-2-enylsulfinylpropanoic acid	1.19	178.01	1.88	$C_6H_{11}NO_3S$	Amino acid
2.	Skimmin	1.24	363.05	2.16	$C_{15}H_{16}O_8$	Coumarin glycoside
3.	Ferulic acid	1.28	193.05	2.35	$C_{10}H_{10}O4$	Phenolic acid
4.	N-dodecanoyl-N-methylglycine	1.28	272.22	1.07	$C_{15}H_{29}NO_3$	Fatty amide
5.	Gamma-carboxyglutamic acid	1.3	190.00	3.16	$C_6H_9NO_6$	Amino acid
6.	Formononetin	1.3	269.13	3.89	$C_{16}H_{12}O_4$	Flavonoid
7.	Gancaonin A	1.31	351.00	2.56	$C_{21}H_{20}O_5$	Flavonoid
8.	1,5-di-O-caffeoylquinic acid	1.4	515.00	6.21	$C_{25}H_{24}O_{12}$	Phenolic acid
9.	3-hydroxybutanoic acid	1.54	105.06	4.6	$C_4H_8O_3$	Organic acid
10.	Pyrogallin	4.53	203.03	4.18	$C_{11}H_8O_4$	Phenolic compound
11.	Undecanoic acid	11.72	185.16	1.17	$C_{11}H_{22}O_2$	Fatty acid
12.	1-hydroxy-2-naphthoic acid	1.64	187.04	1.82	$C_{11}H_8O_3$	Phenolic acid
13.	Dihydrorotenone	20.4	148.93	12.25	$C_{23}H_{24}O_6$	Rotenoid
14.	4-(3-hydroxybutyl) phenol	20.47	149.09	1.56	$C_{10}H_{14}O_2$	Phenolic compound
15.	Ceramide	20.59	722.63	4.41	$C_{42}H_{81}NO_4$	Sphingolipid
16.	Batatasin III	22.52	245.11	2.23	$C_{15}H_{16}O_3$	Stilbenoid
17.	N-acetyltryptophan	22.58	245.15	3.46	$C_{13}H_{14}N_2O_3$	Amino acid
18.	Thymol-β-D-glucopyranoside	25.08	311.15	10.95	$C_{16}H_{24}O_6$	Monoterpene glycoside
19.	S-lactoylglutathione	25.67	251.00	1.8	$C_{13}H_{21}N_3O_8S$	Peptide
20.	Epigallocatechin gallate	25.74	457.14	1.11	$C_{22}H_{18}O_{11}$	Polyphenol
21.	3-O-Acetyldiosgenin	25.77	457.34	1.41	$C_{29}H_{44}O_4$	Steroidal saponin
22.	1-Monostearin	32.62	359.32	1.11	$C_{21}H_{42}O_4$	Lipid

Metabolites were putatively annotated based on accurate mass measurements and by comparing with a database/library.

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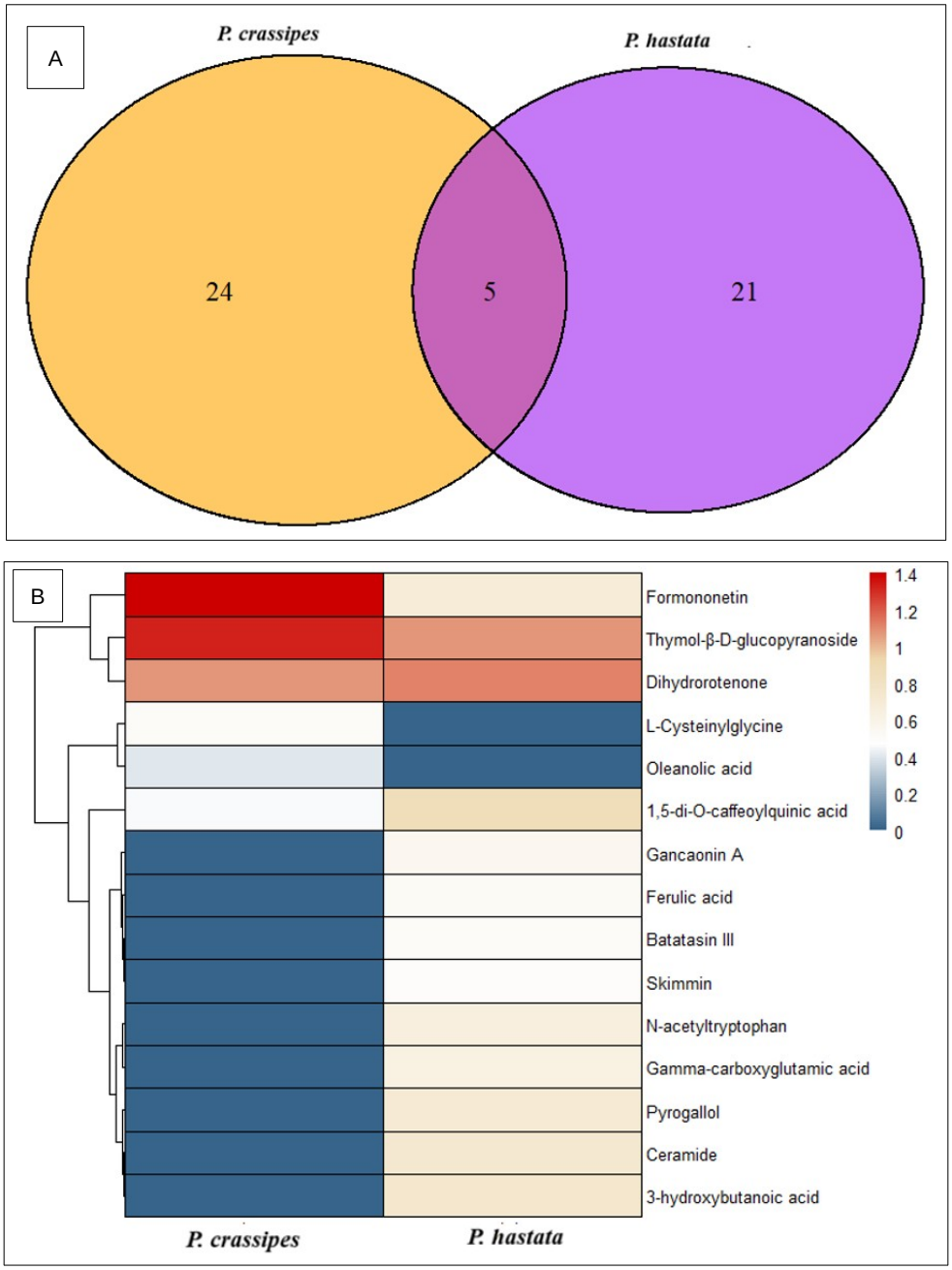


Fig. 4. (A) Venn diagrams showing unique and shared metabolites putatively annotated metabolites in *Pontederia crassipes* and *Pontederia hastata* using liquid chromatography–mass spectrometry (LC–MS); (B) Heatmap showing the top 15 putatively annotated metabolites using LC–MS in *Pontederia crassipes* and *Pontederia hastata*.

Red indicates relatively high and blue relatively low abundance.

Anti-nutritional factor

The anti-nutritional factors, including oxalates, tannins, saponins and phytic acid, observed in the two *Pontederia* species showed that all the anti-nutritional factors were present at low concentrations. The presence of high concentrations of anti-nutritional factors may reduce the bioavailability of minerals and interfere with digestion (28). Comparatively higher estimated total alkaloid and oxalate contents were observed in *P. crassipes*, whereas higher phytic acid, estimated total saponin and tannin contents were observed in *P. hastata*. In comparison with other edible flowers, e.g. *Musa paradisiaca* L., anti-nutritional factors such as oxalate (12.84–15.61 mg/100 g DM) and tannin (11.87–24.04 mg/100 g DM) were present at higher concentrations than those recorded in the present study (29).

Phytochemicals and antioxidant activity

The results for phytochemicals and antioxidant activity indicated clear differences among the three different solvents and between the two species. Methanolic extracts showed higher TPC, TFC and antioxidant activity (DPPH, FRAP and TAC assays) than the aqueous and hexane extracts (30). Comparatively higher TPC, TFC and stronger antioxidant activity were recorded in the methanolic extract of *P. hastata*. Phenolic compounds have hydroxyl groups that can inhibit the production of

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free radicals (31). Flavonoid compounds are the major metabolite classes detected in both species. The findings showed that the ferric reducing capacity of the extracts was due to their polyphenol content, which acts as a reducing agent by donating electrons and reacting with free radicals to convert them into stable forms, thereby terminating the chain reactions of these radicals (32). DPPH scavenging activity in the methanolic extracts of both species showed lower IC_{50} values, which indicated stronger radical scavenging capacities. The lower IC_{50} value recorded for *P. hastata* indicated stronger radical scavenging activity than that of *P. crassipes*. The antioxidant activity can be attributed to the presence of hydroxyl functional groups in phenolic compounds that have redox properties (33). The lower the IC_{50} value, the higher the antioxidant activity; thus, IC_{50} is inversely correlated with antioxidant capacity (34). All the extracts showed comparatively lower antioxidant activity than the standard, ascorbic acid. In the present study, the methanolic extract exhibited the highest TPC, TFC, TAC and FRAP values, as well as the strongest DPPH scavenging activity. Therefore, the methanolic extract was considered for detailed metabolite profiling through GC–MS and LC–MS analyses.

Metabolite comparison

The metabolite profiling performed by GC–MS and LC–MS showed distinct metabolite profiles for the two species, with five putatively annotated metabolites shared between them (Fig. 4A). The different classes of putatively annotated metabolites in *P. crassipes* and *P. hastata* were detected by GC–MS (Fig. 2A). The major putatively annotated metabolites in *P. crassipes*, including the fatty acid methyl esters methyl linolenate and methyl 8-methyl-nonanoate, showed the largest relative peak areas among the reported annotations. Nonanoic acid, putatively annotated in *P. hastata*, is a nutritionally important saturated fatty acid (35). In *P. hastata*, cyclohexanone, 2-methyl-5-(1-methylethenyl) and 2-pyrrolidinone, 1-methyl showed the largest relative peak areas.

The untargeted LC–MS metabolite profiling revealed distinct metabolite profiles for *P. crassipes* and *P. hastata*, even though both species belong to the same genus, *Pontederia*. Among the putatively annotated metabolites, flavonoids were the predominant class in both species, followed by phenolics, glycosides, terpenoids, lipids and amino acid derivatives (Fig. 2B). The presence of putatively annotated phenolic- and flavonoid-related metabolites is associated with the phytochemical findings of the present study. *Pontederia hastata* showed higher TPC, TFC and TAC and stronger DPPH radical scavenging activity than *P. crassipes*, whereas *P. crassipes* showed higher FRAP capacity. The occurrence of phenolic- and flavonoid-related metabolites suggests that the edible inflorescences of both species may contribute to their nutritional and functional food potential. Several putatively annotated metabolites, such as formononetin, thymol-β-D-glucopyranoside, L-cysteinylglycine, 1,5-di-O-caffeoylquinic acid and oleanolic acid in *P. crassipes* and dihydrorotenone, thymol-β-D-glucoside and 1,5-di-O-caffeoylquinic acid in *P. hastata*, exhibited relatively high peak areas. *Pontederia crassipes* was richer in putatively annotated flavonoid and terpenoid metabolites, whereas *P. hastata* showed a greater abundance of putatively annotated phenolic compounds, amino acid derivatives and polyphenols. The hierarchical clustering in the heatmap clearly separated the two species into two groups according to their metabolite profiles (Fig. 4B). The heatmap showed the top 15 putatively annotated metabolites according to relative peak area, such as formononetin, thymol-β-D-glucopyranoside, dihydrorotenone, L-cysteinylglycine and oleanolic acid in *P. crassipes* and skimmin, ferulic acid, 1,5-di-O-caffeoylquinic acid, ceramide, gamma-carboxyglutamic acid, N-acetyltryptophan, gancaonin A and batatasin III in *P. hastata*. However, further confirmation of putatively annotated metabolites using MS/MS fragmentation and authentic reference standards, together with targeted quantitative metabolite studies, is required. Previous studies have reported phytochemical constituents from the leaves, roots and other vegetative parts of *Pontederia* species, but limited information is available on the metabolite composition of edible inflorescences (5, 6). This study reports the comparative LC–MS profiling of the edible flowers of *P. crassipes* and *P. hastata*, which reveals the putative presence of diverse metabolites such as flavonoids, phenolic acids, coumarins, terpenoids, amino acid derivatives and lipid-related metabolites.

Traditional use and food security implications

The nutritional composition, anti-nutritional content and *in vitro* antioxidant activity are relevant in the context of traditional consumption of these inflorescences by the Bodo community of Assam. These findings suggest that these underexplored edible inflorescences are locally available food resources and may contribute to food security. These edible inflorescences could possibly be used as ingredients for functional food products and other value-added products after further evaluation of sensory suitability and toxicity. Even though these edible inflorescences are easily available in the study area, domestication may reduce dependence on wild harvesting.

Conclusion

This study revealed that the inflorescences of *Pontederia hastata* and *Pontederia crassipes* showed distinct nutritional profiles, with considerable amounts of moisture, protein and carbohydrates. Methanolic extracts of both species exhibited greater antioxidant capacity. Gas chromatography–mass spectrometry (GC–MS)-based phytochemical profiling also revealed the presence of some nutritionally important compounds, such as phenolic and fatty acids. Liquid chromatography–mass spectrometry (LC–MS) analysis putatively annotated numerous metabolites such as flavonoids, phenolic acids, terpenoids, glycosides, amino acid derivatives and lipid compounds. These findings provide nutritional and phytochemical information relevant to the traditional practice of consuming these inflorescences. Edible

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inflorescences may have potential applications in food security and supplementary food products. However, further tandem mass spectrometry (MS/MS) confirmation, quantitative profiling, *in vivo* studies and toxicity evaluations are required to validate the putatively annotated metabolites and their associated biological activities.

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Authors' contributions

FSD conceived the study, conducted fieldwork, performed experiments, analysed the data and drafted the manuscript. MD assisted in fieldwork and laboratory experiments. PI contributed to data interpretation and critical revision of the manuscript. RD supervised the work and edited the manuscript. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

The study was conducted in accordance with institutional and ethical guidelines Ref. No: IEC/BU/2026-6.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Quill Bot in order for language editing, including grammar correction and improvement of sentence clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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