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Original Article

LC-ESI-MS/MS-based Phytochemical Profiling and Analysis of the Thermostability of Dietary Antioxidants of a Wild Edible Rattan Species Calamus Floribundus

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Abstract *- Calamus floribundus, a rattan species primarily known for its use in crafting industries, is also valued as a wild edible plant among ethnic communities. Traditional knowledge highlights its tender shoot as a rich source of essential nutrients, bioactive compounds, and dietary antioxidants. This study investigates its nutritional composition, phytochemical profile, antioxidant activity, and thermostability using advanced analytical techniques, including LC-ESI-MS/MS. The results reveal high protein content (23.05%) and significant mineral levels, particularly potassium (3206.91 mg/100g), iron (164.25 mg/100g), and zinc (24.36 mg/100g), surpassing many conventional leafy vegetables. C. floribundus also exhibits strong antioxidant potential, with rich phenolic (64.23 mg GAE/g dm) and flavonoid (43.68 mg RE/g dm) contents contributing to robust free radical scavenging activity.Phytochemical analysis identifies key polyphenols such as chlorogenic, caffeic, rutin, and quercetin. The thermostability study indicates an initial increase in antioxidant content and activity during the first 30 minutes of heat exposure, followed by a gradual but marginal decline. However, activity remains higher than baseline levels. These findings establish C. floribundus as a nutritionally rich, functional food with potential applications in dietary supplementation and sustainable nutrition, particularly in addressing micronutrient deficiencies and promoting health through natural antioxidants.*

Keywords *- Wild edible plants, Phytochemical composition, Rattan species, Minerals, Antioxidants.*

1. Introduction

The health protective and health promoting benefits of many plants, particularly some herbs, tender shoots, fruits and other edible plants, are well documented in ancient texts of India, China, Egypt and Latin America. Throughout millennia, they remained part of ethnic food culture and traditional knowledge and are conserved due to community efforts. Most of these edible plants are lesser known and non-conventional in the sense that they are mostly wild, semi-wild or grow as backyard crops but invariably come from sources other than organized cultivation [1, 2]. Since this food culture is mostly prevalent among rural people and different ethnic communities who are economically downtrodden, such lesser-known edible plants were often referred to as “nutrient-dense but underutilized foods”. Rattan species, primarily from the genus Calamus, possess significant edible potential due to their rich nutritional composition, including essential vitamins, minerals, and bioactive compounds [3]. Traditional knowledge among various indigenous communities highlights their consumption in diverse forms, such as tender shoots and fruits, which serve as vital nutritional and nutraceutical sources in ethnic food practices. Among these, Calamus floribundus has been identified as a non-conventional food plant, with emerging studies exploring its nutritional and functional properties. Investigating the dietary value of rattan species can contribute to sustainable food security and promote their utilization as alternative food resources. Wild edible food plants are known for their rich phytochemical composition, which comprises various dietary antioxidants like phenolics, flavonoids and some other alkaloids [4, 5]. These are secondary metabolites called dietary antioxidants since they are integral parts of food. These are of immense importance since they can effectively scavenge harmful Reactive Oxygen Species (ROS) and other free radicals which are responsible for the onset of many degenerative diseases like cardiovascular diseases, diabetes, cancer, neurodegenerative diseases, inflammatory diseases, etc., being a natural product, they are considered safe and preferred over synthetic antioxidants whose biosafety is questionable [6]. Food items are generally cooked in various manners according to cultural practice, except for fruits and a

few vegetables, which are used as salad. Most antioxidant-rich plants, including wild edible plants, are generally consumed by cooking [7]. Therefore, the study of the thermal stability of dietary antioxidants is of paramount importance from both nutritional viewpoints. For practical purposes, cooking is a high-temperature treatment that causes thermal hydrolysis of major food components like proteins, carbohydrates and lipids to a varied extent. This facilitates the digestion process and is desirable. However, food contains, apart from macronutrients, many micronutrients like vitamins and other phytochemicals whose thermal breakdown is not desirable.

With growing interest in dietary antioxidants because of their established role in health protective and health promoting function, it is necessary to know about their thermostability otherwise, their health benefits will be lost. To study thermostability, the critical factor is to decide on the temperature and time duration, which closely resemble the cooking process.Therefore, the present work was carried out to explore the phytochemical composition of a wild edible rattan species, Calamus floribundus, and to determine the thermostability of its dietary antioxidant. This study aims to provide scientific validation for the traditional use of C. floribundus as a food source. It contributes to the broader exploration of non-conventional edible plants in sustainable nutrition and functional food development.

2. Materials and methods

2.1. Sample Collection and Processing

The tender shoot of the rattan species Calamus Floribundus (CFO) was collected from natural habitats in the months of April to June. The petiole and leaf base were removed from the tender shoot. The cleaned plant material was finely chopped and allowed to dry at room temperature overnight. The finely chopped tender shoot was dried in oven at a constant temperature of 50oC ± 2oC; till constant weight was achieved. Subsequently, the dry sample was grounded to fine powder, kept in a close container, and left in the refrigerator until use.

2.2. Determination of Nutritional Parameters

The present study employed standard methodologies outlined by AOAC [8] for the determination of nutritional parameters. The nutritional composition was determined for protein, carbohydrate, lipid, fibre, ash content, and calorific value. The crude protein content was estimated through the Micro-Kjeldahl method (AOAC 984.13, 981.10). Finely ground dry matter (20 to 40 mg) was subjected to digestion with concentrated Sulfuric Acid (H_2SO_4) in the presence of copper sulfate and potassium sulfate in a 1:2 ratio. The digestion continued until a clear solution was obtained, which was subsequently distilled using a micro-Kjeldahl apparatus. The distillation process involved alkylation with 45% Sodium Hydroxide (NaOH), and the ammonia released was absorbed in 4% boric acid. The resulting solution was titrated against 0.01N Hydrochloric Acid (HCl) with methylene blue-red as an indicator. The nitrogen content was determined and converted into crude protein using an appropriate conversion factor. Lipid content was quantified following the Soxhlet extraction method (AOAC method 2003.06). 4 g of ground dry sample was extracted with petroleum ether at 40–60°C for a duration of eight hours. The extracted lipids were subsequently concentrated under reduced pressure at a temperature of 25°C, dried in an oven set at 50°C, and weighed to determine total lipid content. Crude fibre estimation was performed using AOAC method 962.09. In this process, 4 g of dry sample was digested with 0.225N sulfuric acid (H_2SO_4) for thirty minutes. The mixture was then filtered, and the residue was thoroughly washed with distilled water until neutral. Under identical conditions, the residue was subjected to further digestion with 0.313N Sodium Hydroxide (NaOH). After filtration and washing, the residue was allowed to dry overnight at room temperature before being transferred to an oven at 50°C.

The percentage of crude fibre was calculated gravimetrically. The ash content was determined using AOAC method 942.05. For this purpose, four grams of dry sample were incinerated in a silica crucible at 630°C for three hours in a muffle furnace. After cooling to room temperature, the crucible was weighed to determine the total ash content, which was expressed as a percentage of dry weight. Total carbohydrate content was quantified using the anthrone method [9]. One hundred milligrams of dry sample was hydrolyzed with 2.5N Hydrochloric Acid (HCl) for three hours in a boiling water bath. The digested mixture was subsequently neutralized with Sodium Carbonate (Na_2CO_3), centrifuged, and diluted to a final volume of 100 mL. The total carbohydrate content was determined spectrophotometrically using an anthrone reagent, with absorbance measured at 630 nm. A standard glucose calibration curve was employed for quantification. The calorific value of the samples was calculated based on the macronutrient composition using the energy conversion factors provided by [10]. The calorific value (kcal/100g) was computed using the formula:

$$\text{Energy (kcal)} = (4 \times \text{Protein}) + (4 \times \text{Carbohydrate}) + (9 \times \text{Lipid}).$$

2.3. Determination of Mineral Profile

The mineral profile of the samples was analyzed according to respective AOAC methods [8] for mineral estimation. Sodium and potassium were extracted using the dry ash method (AOAC 935.13) and quantified using a flame photometer. Calcium and magnesium were extracted via the wet ash method (AOAC 935.13) and quantified using an Atomic Absorption Spectrophotometer (AAS). Iron and zinc contents were determined using AAS, following AOAC method 999.10. Phosphorus concentration was determined using the gravimetric method (AOAC 964.06).

2.4. Phytochemical Extraction

The extraction of phytochemical constituents from CFO was carried out using a hydroalcoholic solvent system comprising 80% methanol, a previously validated methodology for its efficacy in isolating diverse phenolic compounds [11]. The extraction of phytochemicals was carried out from 5 g of ground dry matter under continuous agitation for 6 hours at room temperature in 100 mL of 80% methanol. Subsequently, the mixture was sonicated for 30 minutes, followed by an additional extraction phase in a water bath shaker at 40°C for 90 minutes. The resulting extract was centrifuged and concentrated using a rotary evaporator at 35°C, followed by lyophilization of the remaining portion. A portion of the lyophilized extract was subsequently reconstituted in HPLC-grade methanol for comprehensive phytochemical analysis.

2.5. Estimation of Total Phenolic and Flavonoid Content

Quantitative determination of Total Phenolic Content (TPC) was conducted employing the Folin-Ciocalteu spectrophotometric method [12], and the result was expressed as Gallic Acid Equivalent (mg GAE/g dm). For TPC estimation, 100 µL diluted extract was taken in a tube containing 2.9 mL distilled water, followed by adding 0.5 mL Folin-Ciocalteu reagent. The components were homogenized and allowed to stand for 3 min at room temperature. Thereafter, 2 mL of 20% Na2CO3 was added, and tubes were immediately transferred to a water bath set at 70ºC and incubated for 1 min. The absorbance of the coloured complex was recorded at 650 nm using a UV-VIS spectrophotometer (Thermo Scientific, USA).

The Total Flavonoid Content (TFC) was quantified utilizing the aluminium chloride colorimetric method [13], and the result was expressed as rutin equivalent (mg RE/g dm). Briefly, 100 µL of diluted extract was taken, adding 3 mL of distilled water. 100 µL 80% methanol was taken separately as reaction blank, and 3 mL distilled water was added. This was followed by adding 300 µL of 5% $NaNO_3$ and allowed to stand for 5 min at room temperature. After that, 600 µL of 10% AlCl3 was added and allowed to stand for 6 min at room temperature. Finally, 2 mL of 1M NaOH was added to develop a red-colored complex, and the absorbance was recorded at 510 nm using a UV-VIS spectrometer (Thermo Scientific, USA).

2.6. In Vitro Antioxidant Activities

The antioxidant potential of the reconstituted crude extract was evaluated using multiple in vitro antioxidant assays. These comprised the 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) radical scavenging assay [14], Trolox Equivalent Antioxidant Capacity (TEAC) assay [15], Ferric Reducing Antioxidant Power (FRAP) assay [16], and the phosphomolybdate assay for Total Antioxidant Capacity (TAC) [17]. These assays were carried out per standard methodologies using about 100 µL reconstituted CFO crude extract. The IC_{50} values of DPPH and ABTS reduction were determined from a gradually increasing concentration of the crude extract and the measurement of free radical scavenging by a fixed extract volume. Moreover, the FRAP, TEAC and TAC values were expressed as Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) Equivalent (TE) for comparison. This comprehensive analytical approach enabled a thorough evaluation of the extract's antioxidant properties through multiple mechanistic pathways.

2.7. LC-MS/MS Analysis

Different phytochemicals from the crude extract were screened using an Agilent, 6410 triple quad LC/MS system. For this determination, 5 µL of reconstituted lyophilized crude extract was injected using an autosampler into a reverse-phased column (length 100 mm, internal diameter 4.6 mm, particle size 3.5 µm, part no. 959961-902, Agilent) which was thermostatically maintained at 40°C. The mobile phase was comprised of 0.1% Formic Acid (A) in water and Methanol (B).

The flow rate of the LC system was maintained at 0.4 mL/min. The gradient LC separation program was 2% B for 0 min and 3 min, 25% B for 6 min, 50% B for 10 min, 95% B for 14 min and 17 min, and 2% B for 18 min and 20 min. The DAD detector was set at 280 nm, and MS and MS/MS acquisition parameters were as follows: ESI mode was set to negative; m/z scan range of 100 to 1000; ESI drying, nebulization and collision gas was nitrogen and argon; MS temperature was 120ºC; capillary and core voltage was 40 kV.

2.8. Isothermal Degradation Kinetics

To study the thermostability of antioxidants and isothermal degradation kinetics, 1 g fresh tender shoot of CFO was chopped and grounded using mortar and pestle and then transferred into a 250 mL leakproof reagent bottle, and 25 mL of distilled water was added. The samples were then transferred to a hot air oven set at 100ºC and homogenized periodically for 150 minutes. 1 mL of aliquot was withdrawn within 30-minute intervals, and the total phenolics content, flavonoid content, and in vitro antioxidant activity were determined using the DPPH-RSA method. The increase/loss in estimations was recorded. The kinetic model of isothermal degradation was described by first-order kinetics

$$C/C_0 = e^{-kt}$$

2.9. Statistical Analysis

All the statistical analysis were carried out in SPSS Statistics v28.0 (IBM Corp, United States). The cure fitting and data visualization was carried out in Origin Pro (v2024b). Three replications were carried out for all the experiments generating quantitative data to determine the statistical variance mean ± Standard Error of the Mean (SEM).

3. Results and Discussion

3.1. Nutritional Parameters and Mineral Profile

Calamus Floribundus (CFO) demonstrates a rich nutritional composition, making it a significantly important food plant (Figure 1). The tender shoots exhibited a moisture content of 88.36%, comparable to other leafy vegetables. Notably, CFO contains a substantial protein content of 23.05%, which is higher than many conventional leafy vegetables. Its carbohydrate content (9.88%) is considerably lower than several leafy vegetables [18]. Lipid content in CFO remains low at 1.28%, making it a suitable dietary option for individuals seeking low-fat food sources. The ash content, a measure of total minerals, is significant at 14.36%, indicating its potential as a mineral-rich plant food. Due to the low carbohydrate and lipid content in CFO, the calorific value was low. The major contributor for calorific value was protein. Recently, considerable information about the nutritive value of a sizeable number of non-conventional food plants, particularly wild and semi-wild leafy vegetables, has been generated.

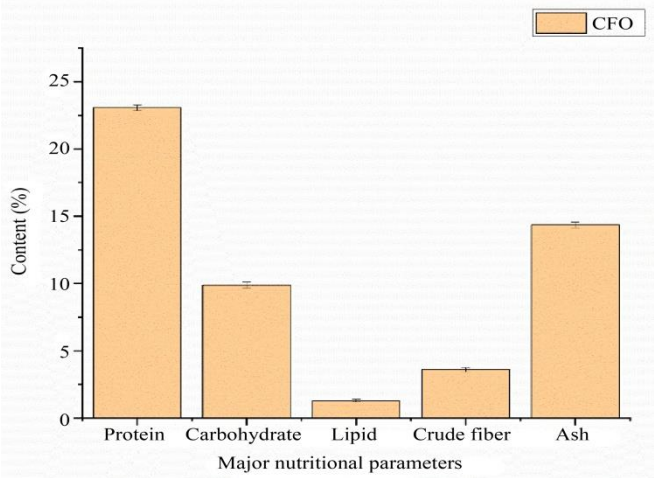

Fig. 1 Major nutritional parameters in C. floribundus

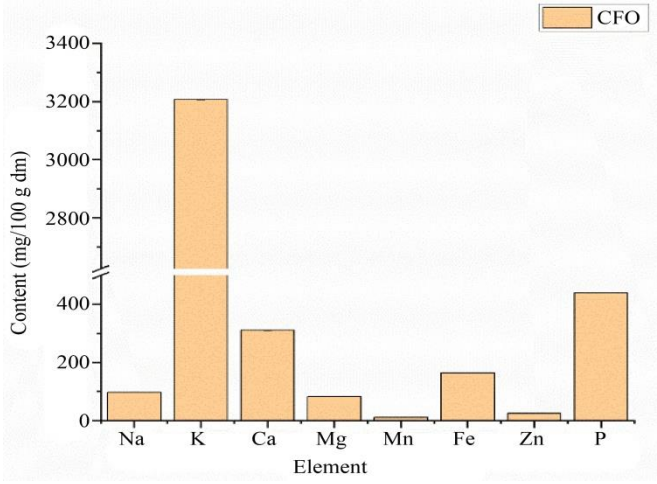

Fig. 2 Profile of some macromineral and micro mineral elements in C. floribundus

Extensive work by Handique and coworkers has revealed a general trend - many wild edible plants are particularly rich in protein, total mineral (ash content) and crude fibre while containing relatively low amounts of total carbohydrates and lipids [1, 18].The mineral profile of plant food is of utmost importance. Only plants can uptake various minerals present in the soil through their root system. Plant food is generally regarded as the primary source of minerals. The mineral profile of CFO highlights its considerable nutritional advantage (Figure 2). Among the macro minerals, potassium is the most abundant (3206.91 mg/100g), significantly surpassing other rattan species [3]. The contents of calcium (310.34 mg/100g) and magnesium (282.26 mg/100g) also occur in significantly higher amounts. The findings for the three micro minerals in the present study were impressive compared to macro minerals.

The micro-mineral profile shows CFO as an excellent source of iron (164.25 mg/100g); zinc (24.36 mg/100g) was also found to be present in substantial quantities, surpassing the levels found in many leafy vegetables. These results align with previous studies on edible rattan species, such as C. tenuis and C. thwaitesii, which also reported high protein and mineral content while maintaining a low carbohydrate profile [3, 19]. One of the best findings of the present study is a reasonably high amount of iron. The Recommended Dietary Allowance (RDA) of iron for adult men and women in India are 17 mg/day and 21 mg/day. On a dry weight basis, CFO contains eight times more iron than the prescribed RDA, which is remarkable. These findings underscore the potential of CFO as a nutritionally dense food source, particularly for populations relying on traditional food systems.

3.2. Dietary Antioxidants and in Vitro Antioxidant Activity

Antioxidants play a crucial role in protecting biological systems from oxidative stress, and CFO emerges as a promising dietary source of antioxidants. The study of dietary antioxidants is becoming increasingly important because it is a well-established fact that oxidative damage by various free radicals initiates a number of degenerative diseases [20], and dietary antioxidant is a powerful remedy for this. CFO's Total Phenolic Content (TPC) was recorded at 64.23 mg GAE/g Dry Matter (dm). Likewise, the Total Flavonoid Content (TFC) was 43.68 mg RE/g dm, suggesting the presence of potent flavonoid compounds contributing to its antioxidant properties.

These values indicate superior antioxidant potential compared to several conventional plant foods [4, 5]. CFO's in vitro antioxidant activity was assessed using multiple assays, including radical scavenging assays viz. DPPH, ABTS and TEAC; reducing power assay FRAP and TAC (Table 1). The DPPH assay revealed a strong radical scavenging activity, with an IC_{50} value of 0.021 mg/mL, stronger than conventional and non-conventional leafy vegetables [21, 22]. Similarly, the ABTS assay yielded an IC_{50} value of 0.031

mg/mL, demonstrating CFO's superior antioxidant efficacy. TEAC and FRAP assays further confirmed their antioxidant potential, with CFO recording 1064.21 μM TE/g dm and 5172.36 μM TE/g dm, respectively. These findings support previous research indicating that non-conventional food plants, particularly rattan species, possess high antioxidant activity due to their polyphenolic and flavonoid-rich composition [4, 23]. The superior antioxidant profile of CFO suggests its potential as a functional food ingredient with protective effects against oxidative stress-related disorders. In the backdrop of these reasoning, there was an upsurge in the search for natural antioxidants among different plants. Because external antioxidant supplements were a growing necessity in view of ever-growing non-infectious lifestyle diseases. Being secondary metabolites of plants, these are natural compounds, so there is no concern about biosafety. Since there are a large number of conventional and non-conventional food plants, many of which are underutilized and little explored, the possibility of exploring dietary antioxidants is unlimited. More importantly, dietary antioxidants are found mostly in plants.

3.3. Phytochemical Profile

The phytochemical composition of CFO was analyzed using LC-ESI-MS/MS, revealing a diverse range of bioactive compounds. The UV-DAD detection chromatogram and ESI-MS/MS total ion chromatogram are represented in Figure 3. CFO exhibited notable polyphenolic compounds, including caffeic acid, chlorogenic acid, quercetin, and rutin (Table 2). The presence of chlorogenic acid is particularly significant, as this compound has been associated with anti-inflammatory and neuroprotective effects [24, 25]. Additionally, CFO is comprised of ferulic acid, a potent antioxidant known for its role in scavenging free radicals and enhancing cellular defense mechanisms [26]. Moreover, previous studies suggest that phytochemical profiles similar to CFO have potential effects on glycemic control [27, 28]. Dietary antioxidants from wild edible plants like CFO can be a food-based remedy for glycemic control and, thereby, prevent diseases like type II diabetes mellitus. The present study's findings reinforce CFO's status as a nutritionally valuable species with potential applications in nutraceutical and functional food industries and dietary remedy for some lifestyle diseases.

Table 1. The content of total phenolics, flavonoids, and in vitro antioxidant activities was assessed by different assay methods in C. floribundus

Type of Study	Content
Dietary antioxidants	
TPC (mg GAE/g dm)	64.23 ± 0.421
TFC (mg RE/g dm)	43.68 ± 0.417
In vitro antioxidant activity	
DPPH IC50 (mg/mL)	0.021
ABTS IC50 (mg/mL)	0.031
TEAC (μM TE/g dm)	1064.21 ± 0.926
FRAP (μM TE/g dm)	5172.36 ± 1.219
TAC (mM TE/g dm)	20.72 ± 0.211

Table 2. LC-ESI-MS/MS profiling of crude extract of C. floribundus

SN	Compound name	RT (min)	Adduct	Fragment ions
1	Quinic acid derivative	1.98	[M-H]-	114, 132, 191, 254
2	Caffeic acid	2.25	[M-H]-	110, 134, 181
3	Caffeoylquinic acid	2.40	[M-H]-	110, 134, 191, 254
4	Chlorogenic acid	6.28	[M-H]-	191, 331, 353
5	Rutin	9.35	[M-H]-	233, 467, 609, 610
6	Ferulic acid	10.2	[M-H]-	134, 149, 159, 178, 193
8	Quercetin	12.8	[M-H]-	113, 195, 301, 302
9	Quercetin-3β-D-glucoside	13.1	[M-H]-	271, 255, 300, 301, 463

3.4. Thermostability of Antioxidants

The study of the thermostability of dietary antioxidants is paramount from both nutritional and academic viewpoints. The thermostability of dietary antioxidants is crucial in determining their retention during cooking and processing. With growing interest in dietary antioxidants because of their established role in health protective and health promoting function, it is necessary to know about their thermostability; otherwise, their health benefits will be lost during processing. To study thermostability, the critical factor is to decide on the temperature and time duration, which closely resemble the cooking process. Plant foods, i.e., grain food, vegetables, etc., are generally subjected to wet cooking, i.e., cooking with water and other ingredients, and hence, 100°C can be considered a representative temperature. The present study assessed the thermostability of CFO's antioxidants under isothermal cooking conditions (Figure 4). Results indicate total phenolic and flavonoid contents exhibit stability under mild heat treatment but marginal degradation upon prolonged duration (150 minutes).

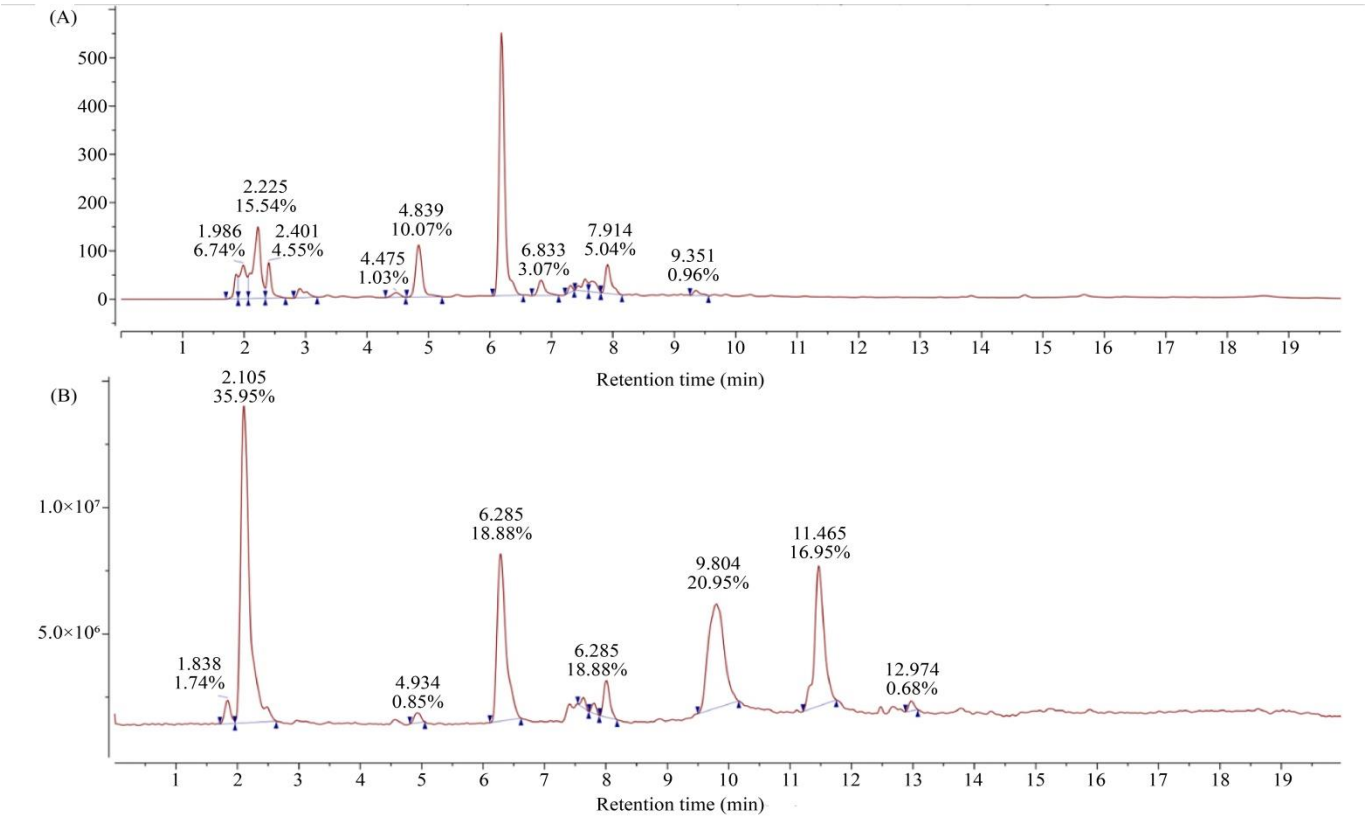

Fig. 3 LC-ESI-MS/MS determination of phytochemical composition of C. floribundus: (a) UV-DAD chromatogram, and (b) Total ion chromatogram in ESI (-ve) mode.

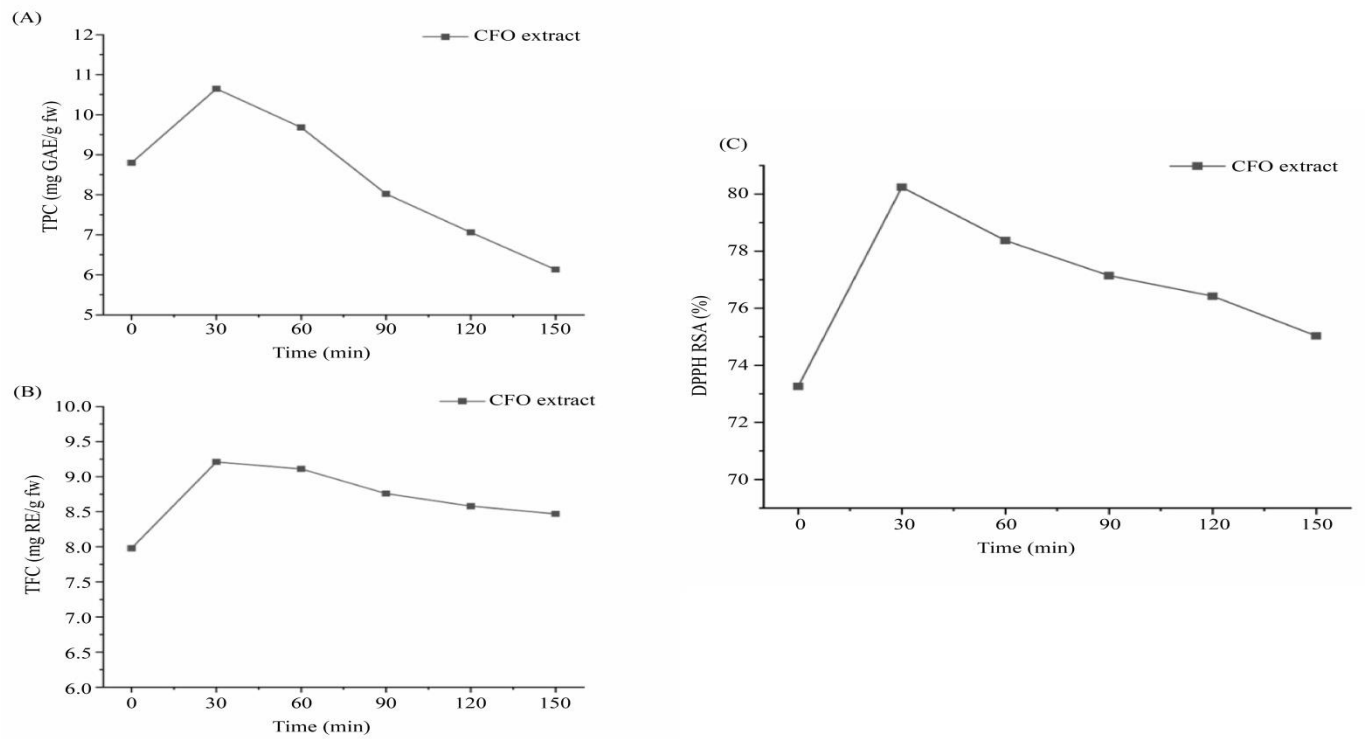

Fig. 4 Isothermal degradation of total phenolic content (a) Total flavonoid content, (b) In vitro radical scavenging activity, and (c) of C. floribundas antioxidants.

Moreover, no phenolic and flavonoid content reduction was observed at 30-minute intervals starting from 0 to 150 min, whereas their contents increased marginally in the initial period (Figure 4, (a) & (b)). The DPPH assay that was conducted post-thermal treatment further corroborated these findings. While antioxidant activity was retained for up to 90 minutes, it declined marginally to 150 minutes (Figure 4(c)), suggesting partial decomposition of phenolic and flavonoid compounds. The isothermal degradation constants for TPC, TFC and DPPH-RSA for CFO extract were found to be -0.0389, -0.0067 and -0.0412, respectively. These observations are consistent with previous studies on wild edible plants, where flavonoids and polyphenols exhibited varying degrees of thermal sensitivity [29, 30].

The present study shows that three trends become clear following heat treatment: (1) there was an increase up to a threshold limit of 30 minutes for phenolics and flavonoids. Beyond that, there is a limited decline in a linear manner depending on the duration. Despite the observed decline, the values are mostly higher than baseline values from zero minutes. Secondly, (2) flavonoids exhibited higher thermal stability compared to phenolics (3) In vitro antioxidant activity also show a proportionate initial increase up to the threshold limit of 30 minutes and then a linear but limited decline. However, the in vitro antioxidant activity remained higher than the baseline value of 0 minutes. Therefore, the thermostability pattern of phenolics, flavonoids and in vitro antioxidant activity trends complement each other. The findings of the present work conform with those of several other workers who observed distinct patterns of initial increase of polyphenolic compounds upon heating or far infrared radiation.

Jeong and coworkers [31]reported the relationship between heating temperature and time duration on the changes in phenolic content in citrus peel. It was observed that irrespective of whether ethanol extract or water extract, phenolic content increased when subjected to a temperature range of 50^{o}C to 150^{o}C from 0 to 60 minutes. It was reasoned that many phenolic components remain bound to tissue or cell walls, and heating releases them, increasing phenolic content. Another work involving far-infrared radiation showed an increase in the phenolic compound of rice hulls [32]. The authors explained that heat treatment could sometimes not cleave the phenolic compounds covalently bound to the matrix. However, far infrared radiation is capable of cleaving the covalent bond to liberate antioxidants like flavonoids, carotene, tannin and other polyphenols from repeating polymers. This increased total phenolics then the baseline value obtained at room temperature.

4. Conclusion

The present study highlights the nutritional, phytochemical, and functional attributes of tender shoots of Calamus floribundus, a wild edible rattan species with significant potential as a non-conventional food plant. The species exhibits a rich nutritional profile, with high protein content and abundant essential minerals such as potassium, iron, and zinc, surpassing many conventional vegetables. Its remarkable antioxidant capacity, attributed to polyphenolic compounds including chlorogenic acid, rutin, and quercetin, underscores its potential role in combating oxidative stress-related disorders. The study also provides critical insights into the thermostability of its dietary antioxidants. It demonstrates that phenolic and flavonoid compounds exhibit initial enhancement upon heating, likely due to the release of bound phytochemicals, followed by a gradual decline over extended exposure.

Despite this partial degradation, antioxidant activity remains significantly higher than baseline levels, suggesting substantial thermal resilience. These findings validate the traditional use of C. floribundus as a functional food while emphasizing its potential contribution to sustainable nutrition, particularly in regions reliant on wild edible plants for dietary diversity. The high mineral content suggests its application in addressing micronutrient deficiencies, while its robust antioxidant stability makes it a promising candidate for nutraceutical formulations. Future research should focus on bioavailability studies, glycemic control aspects, metabolic pathways, and food processing adaptations to optimize its dietary benefits. Dietary consumption of tender shoots C. floribundus has immense potential as a sustainable, health-promoting dietary component, fostering greater utilization of non-conventional food plants in functional food development.

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