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Original Article

PHENOLIC AND ANTIOXIDANT ALTERATIONS IN WILD EDIBLES UNDER DIFFERENT COOKING METHODS

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ABSTRACT

Objective: Polyphenols and antioxidants in plants support human health by reducing oxidative stress. In North-East India, many wild and cultivated plants are traditionally valued for their nutritional and medicinal benefits. However, the impact of different cooking methods on their polyphenol content and antioxidant activity remains underexplored.

Methods: This study assessed the impact of boiling and microwave cooking on the total phenolic content (TPC) and antioxidant activity of ten commonly consumed plants from North-East India, including *Meynia laxiflora*, *Castanopsis indica*, *Docynia indica*, *Flemingia vestita*, *Bauhinia purpurea*, *Dillenia pentagyna*, *Diplazium esculentum*, *Elaegnus latifolia*, *Elaegnus pyriformis*, and *Fagopyrum cymosum*. Antioxidant properties were evaluated using DPPH and ABTS radical scavenging assays, reducing power capacity, and measurements of TPC, total flavonoid, and flavonol content.

Results: Total phenolic content (TPC) in fresh samples ranged from 46.67 to 2760.05 mg per 100 gs (dry weight). Antioxidant activity, measured using 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, ranged from 9.04% to 93.06%, while the 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay showed values ranging from 15.45% to 82.11%. Boiling caused considerable losses in TPC (up to 25.26%) and antioxidant activity (DPPH: 25.23–30.80%; ABTS: 9.06–36.03%). In contrast, microwave cooking preserved or enhanced TPC (increased up to 13.36%) and antioxidant activity (DPPH: 11.11–36.34%; ABTS: 5.72–24.32%).

Conclusion: Microwave cooking is more effective than boiling in preserving or enhancing the phenolic content and antioxidant activity of wild edible plants. It is therefore recommended to retain their maximum health benefits.

Keywords: Wild edible plants, Antioxidant activity, Cooking methods

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INTRODUCTION

In many developing nations, wild edible plants are crucial food sources, especially in rural areas facing population growth, limited farmland, and rising food costs. These plants, often foraged from natural habitats, offer a low-cost, accessible alternative to cultivated crops. Deeply rooted in cultural traditions and dietary practices, wild vegetables grow freely without the need for formal agriculture. Recently, there has been growing interest in evaluating their nutritional value, as they provide not only proteins and energy but also essential vitamins, minerals, and hormone precursors vital for health. Rich in macronutrients like proteins and carbohydrates, these plants help reduce the risk of chronic diseases such as cancer, diabetes, and heart ailments. Their nutrient diversity makes them especially valuable in areas where access to commercial foods is limited. As awareness of their health benefits increases, further research, documentation, and promotion of wild edible plants are essential to support food security and public health in developing regions [1].

Phenolic compounds are plant-based nutrients with strong antioxidant properties. They include phenols, phenolic acids, and flavonoids. These antioxidants neutralize reactive oxygen species (ROS), reducing oxidative stress linked to aging-related diseases like cancer, heart disease, and neurodegeneration. By limiting cellular damage, phenolic compounds help protect against chronic conditions and support overall health [2, 3].

Recent studies emphasize that fruits and vegetables are rich sources of natural antioxidants such as vitamins C and E, carotenoids like beta-carotene, flavonoids, and phenolic compounds. These bioactive substances help combat oxidative stress caused by free radicals, which is a key contributor to aging and chronic diseases like cancer, cardiovascular disorders, and neurodegeneration [4-6]. Antioxidants stabilize harmful molecules, protecting cells and tissues from damage. Growing evidence highlights the health benefits of a diet high in fruits and vegetables, including reduced risk of chronic conditions and improved immune function. Vegetables, in particular, offer long-term protection against age-related issues such as cataracts and macular degeneration. Their high antioxidant content not only reduces oxidative damage but also helps lower inflammation and enhance overall health. As a result, regular consumption of fruits and vegetables is essential for preventing age-related diseases and promoting healthy aging and longevity [7].

Vegetables are often boiled or microwaved before consumption, which can alter their chemical properties. Studies show that boiling or baking tomatoes retains their phenolic content and antioxidant activity, while frying reduces it. Similarly, cooking methods impact broccoli's antioxidants, and thermal processing in vegetables like kale, spinach, and cabbage often leads to a reduction in total phenolic content and, at times, antioxidant activity, as reported by Zhang, Hamauzu, and others [8–10].

A recent study evaluated the effects of boiling and microwave cooking on total phenolic content (TPC) and antioxidant activity in wild edible plants from North-East India, including *Perilla ocymoides*, *Clerodendrum colebrookeanum*, *Solanum gilo*, *Solanum kurzii*, and *Potentilla lineata*. Antioxidant activity was measured using DPPH, ABTS, and related assays. Boiling significantly decreased TPC (by 10.90% to 25.66%) and reduced antioxidant potential, while microwave cooking led to an increase in TPC (2.20% to 11.80%) and improved antioxidant activity. These findings suggest that microwave cooking is more effective in preserving health-promoting compounds in these plants [11].

Vegetables such as green beans, peas, peppers, squash, broccoli, leeks, and spinach are often consumed after cooking, and wild vegetables are similarly prepared. However, limited data exists in the scientific literature regarding the effect of cooking methods on the antioxidant activity and total phenolic content of these wild

vegetables. Therefore, this study aims to investigate how different cooking methods, specifically boiling and microwaving, affect the antioxidant activity and total phenolics of *Meynia laxiflora*, *Castanopsis indica*, *Docynia indica*, *Flemingia vestita*, *Bauhinia purpurea*, *Dillenia pentagyna*, *Diplazium esculentum*, *Elaegnus latifolia*, *Elaegnus pyriformis*, and *Fagopyrum cymosum*, collected from different locations in the Meghalaya State of India.

MATERIALS AND METHODS

Plant materials

The fresh edible parts of *Meynia laxiflora* (25.5194° N, 90.2204° E), *Castanopsis indica* (25.5670° N, 91.8830° E), *Docynia indica* (25.4639° N, 91.7132° E), *Flemingia vestita* (25.9020° N, 91.8765° E), *Bauhinia purpurea* (25.4490° N, 92.1983° E), *Dillenia pentagyna* (25.4991° N, 90.2800° E), *Diplazium esculentum* (25.2986° N, 91.5822° E), *Elaegnus latifolia* (25.2886° N, 91.7168° E), *Elaegnus pyriformis* (25.5133° N, 91.2654° E) and *Fagopyrum cymosum* (25.2920° N, 91.7310° E), were collected from various locations in the North eastern region of India. The plant species were identified and authenticated by the Botanical Survey of India in Howrah. Voucher specimens were carefully preserved in the Plant Chemistry Department under the registry numbers BSITS 11, BSITS 12, BSITS 13, BSITS 14, BSITS 15, BSITS 16, BSITS 17, BSITS 18, BSITS 19 and BSITS 20 respectively.

After collection, the plant materials were shed-dried to preserve their nutritional and chemical integrity. Once dried, the plant parts were pulverized into fine powder and stored in airtight containers to prevent moisture and contamination. The effects of different cooking methods, including boiling and microwave treatment, on the antioxidant activity and total phenolic content of these plants were later analyzed in our laboratory.

Chemicals

1,1-Diphenyl-2-picrylhydrazyl (DPPH), 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), butylated hydroxytoluene (BHT), ascorbic acid, quercetin were purchased from Sigma Chemical Co. (St. Louis, MO, USA)., Folin-Ciocalteus's phenol reagent, gallic acid, potassium ferricyanide, potassium per sulphate, Aluminium chloride, $FeCl_3$ and sodium carbonate were from Merck Chemical Supplies (Damstadt, Germany). All the chemicals used including the solvents, were of analytical grade.

Cooking by boiling

For each powdered plant sample (5g), the material was boiled in distilled water at 100 °C in a ratio of 1:10 (weight/volume) on a hot plate. The boiling process was carried out for one hour, during which time the plant materials softened, and their components were sufficiently extracted into the water. After boiling, the plant residues were separated from the liquid using a sieve, ensuring all solid particles were removed. The boiled plant material was then placed in an air oven and dried at 50 °C for two hours. Once fully dried, the samples were stored for further investigation into their antioxidant activity and total phenolic content [12].

Cooking by microwave heating

For each plant sample (5g), the powdered material was placed in a glass beaker containing distilled water in a 1:10 (weight/volume) ratio. The mixture was then subjected to microwave cooking on high power for 15 min, during which time the plants softened. Once the cooking process was complete, the plant materials were separated from the water using a sieve to remove any excess liquid. The softened plant material was then transferred to an air oven, where it was dried at 50 °C for two hours to ensure proper dehydration. After drying, the samples were preserved for further analysis, focusing on their antioxidant activity and total phenolic content [12].

Extraction of plant material

For each plant sample, 100 g of both the raw dried material and the cooked plant material were used for extraction. The extraction process involved two successive treatments with 80% aqueous ethanol. Each extraction was performed with continuous agitation over a period of 18 to 24 h at room temperature. After each round of extraction, the resulting ethanol solutions were combined. To concentrate the extracts, the pooled ethanol solutions were subjected to reduced pressure using a rotary evaporator. This process evaporated the solvent, leaving behind a thick, viscous extract. These viscous extracts were then further dried using a freeze dryer, which removed any remaining moisture, yielding a powdered extract. Both the dried extracts from the raw and cooked plant samples were stored at a temperature of-20 °C to preserve their stability until further use.

The dried extracts obtained from the 80% aqueous ethanol extractions were carefully weighed, and the percentage yield of the extracts was calculated relative to the air-dried weight of the plant materials. This allowed for a precise comparison of the extractable content between raw and cooked samples.

Estimation of total phenolic content

The total phenolic content (TPC) of the crude plant extracts was measured using the Folin-Ciocalteu method [13]. To begin, 100 µl** of the plant extract samples were transferred into test tubes. Then, 1.0 ml of Folin-Ciocalteu reagent was added, followed by 0.8 ml of sodium carbonate solution (7.5%). The mixture was thoroughly mixed and allowed to react for 30 min at room temperature. After the reaction period, the absorbance of the solution was measured at 765 nm using a Shimadzu UV-1800 UV-visible spectrophotometer. The total phenolic content was quantified and expressed in terms of gallic acid equivalents (GAE) in miligram per 100 g (mg/100g) of dry plant material using the following equation based on the calibration curve $y = 0.0013x+0.0498$, $R^2 = 0.999$ where y was the absorbance measured and x was the Gallic acid equivalent concentration. This equation allowed for the precise determination of phenolic content from the absorbance readings.

Estimation of total flavonoids

The total flavonoid content was determined following the method described by Ordonez *et al.* (2006) [14]. To perform the analysis, 0.5 ml of the plant extract was mixed with 0.5 ml of a 2% aluminum chloride ($AlCl_3$) solution prepared in ethanol. The mixture was allowed to stand at room temperature for one hour. After this incubation period, the absorbance of the solution was measured at 420 nm using a Shimadzu UV-1800 UV-visible spectrophotometer. The development of a yellow color in the solution indicated the presence of flavonoids. To quantify the total flavonoid content, it was expressed in terms of rutin equivalents (mg/100g of dry plant material). This was calculated using the calibration curve $y = 0.0182x-0.0222$, $R^2 = 0.9962$, where y represents the absorbance and x is the Rutin equivalent concentration. This equation was used to estimate the flavonoid content in the tested samples.

Measurement of reducing power

The reducing power of the plant extracts was evaluated using the method outlined by Oyaizu [15]. In this procedure, 100 µl** of the plant extract was mixed with 2.5 ml of phosphate buffer (0.2 M, pH 6.6) and 2.5 ml of 1% potassium ferricyanide solution. The mixture was incubated at 50 °C for 20 min. Following incubation, 2.5 ml of 10% trichloroacetic acid was added to the solution, which was then centrifuged at 3000 rpm for 10 min. After centrifugation, the upper layer (2.5 ml) was carefully removed and mixed with 2.5 ml of distilled water and 0.5 ml of freshly prepared ferric chloride solution (0.1%). The absorbance of this final mixture was measured at 700 nm using a UV-visible spectrophotometer (Shimadzu UV-1800). The reducing power was expressed as ascorbic acid equivalents (AAE) in milligrams per 100 gs (mg/100g) of dry plant material. The calculation was performed using the calibration curve equation: $y = 0.0023x-0.0063$, $R^2= 0.9955$ where y represents the absorbance and x is the concentration of ascorbic acid equivalent. This equation enabled the determination of the reducing power of the plant extracts in terms of antioxidant capacity.

Determination of DPPH free radical scavenging activity

The free radical scavenging activities of the plant samples, were assessed using the stable radical DPPH (1,1-diphenyl-2-

picrylhydrazyl) [16]. Aliquots (100 µl**) of each sample were added to separate test tubes. To each tube, 3.9 ml of freshly prepared DPPH solution (25 mg/l in methanol) was introduced and mixed thoroughly. After 30 min, the absorbance of the solution was measured at 517 nm using a UV-visible spectrophotometer (Shimadzu UV 1800). The scavenging ability of the DPPH radical was calculated using the following equation

$$\text{DPPH scavenged (\%)} = \{(Ac - At)/Ac\} \times 100$$

Where A_c is the absorbance of the control reaction and A_t is the absorbance in the presence of the sample of the extracts. The antioxidant activity of the extract was expressed as a percentage inhibition of DPPH radicals by the extract.

2.10 Scavenging activity of ABTS radical cation

The ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) radical cation ($ABTS^{\bullet+}$) scavenging activity was assessed following the method outlined by Re *et al.* (1999) [17]. ABTS was dissolved in water to obtain a 7 mmol concentration. The ABTS radicals were generated by adding potassium persulfate to a final concentration of 2.45 mmol. The radical generation was allowed to proceed in the dark at room temperature for 12–16 h. After this period, the solution was diluted with ethanol to achieve an absorbance of 0.70±0.02 at 734 nm. To measure scavenging activity, 1 ml of the diluted $ABTS^{\bullet+}$ solution was mixed with 10 µl** of the plant extract (or water for the control). The absorbance was measured at 734 nm 6 min after mixing, with ethanol used as the blank. The percentage of inhibition was calculated using the following equation:

$$\text{ABTS scavenged (\%)} = (Ac - As)/Ac \times 100$$

Where A_c and A_s are the absorbences of the control and of the test sample, respectively. The antioxidant activity of the extract was expressed as percentage of inhibition of ABTS radicals by the extract.

Value are presented as the mean±standard error mean of three replicates. The total phenolic content, flavonoid content, reducing power and radical scavenging activities of each plant extract were calculated using linear regression analysis.

RESULTS AND DISCUSSION

The total phenolic content of the vegetables is detailed in table 1. The phenolic content ranged from 46.67±1.23 mg GAE/100g to 2760.05±12.29 mg GAE/100g. The vegetables were ranked based on their total phenolic content as follows: *C. indica* exhibited the highest phenolic content, followed by *D. indica*, *B. purpurea*, *F. vestita*, *F. cymosum*, *D. esculentum*, *E. pyriformis*, *E. latifolia*, *M. laxiflora*, and *D. pentagyna*, which had the lowest phenolic content.

Table 1: Antioxidant properties of wild edible plants and effect of cooking

		TPC (mg GAE/100g)	TFC (mg RE/100g)	RP (mg AAE/100g)	DPPH (% inhibition)	ABTS (% Inhibition)
M. laxiflora	Raw	79.75±2.23	47.69±2.38	74.90±3.68	28.55±5.34	35.88±4.85
	Boiled	68.36±2.09 (-14.28%)	39.67±3.54 (-16.82%)	61.49±4.11 (-17.90%)	19.76±3.68 (-30.80%)	26.99±2.34 (-24.78%)
	Microwave cooking	71.69±1.22 (-10.10%)	53.48±2.07 (+12.14%)	69.28±3.44 (-7.50%)	34.56±2.08 (+21.06%)	39.62±3.75 (+10.43%)
C. indica	Raw	2760.05±12.29	118.84±2.07	139.65±13.68	93.06±4.33	82.11±4.27
	Boiled	2678.11±8.47 (-2.96%)	87.44±3.18 (-26.42%)	97.54±4.64 (-30.16%)	68.76±3.19 (-26.11%)	71.04±3.39 (-13.47%)
	Microwave cooking	2818.44±11.19 (+2.12%)	101.23±4.09 (-14.82%)	102.56±5.18 (-26.56%)	86.77±2.58 (-6.76%)	91.24±2.37 (+11.13%)
D. indica	Raw	357.53±7.44	46.84±2.06	75.94±3.98	58.83±2.09	54.55±3.48
	Boiled	307.11±3.45 (-14.10%)	28.76±3.14 (-38.60%)	53.27±4.29 (-29.85%)	43.74±3.56 (-25.66%)	41.67±2.36 (-23.61%)
	Microwave cooking	332.77±2.33 (-6.92%)	53.25±2.38 (+13.68%)	62.27±5.26 (-17.99%)	51.88±7.28 (-11.82%)	63.37±5.29 (+16.18%)
F. vestita	Raw	235.30±2.43	45.31±1.34	65.26±3.45	18.30±2.19	24.05±1.15
	Boiled	213.27±1.25 (-9.36%)	21.54±3.14 (-52.46%)	34.78±7.08 (-46.71%)	13.14±4.64 (-28.19%)	18.66±3.86 (-22.42%)
	Microwave cooking	245.67±3.33 (+4.40%)	37.89±2.66 (-16.37%)	51.87±5.25 (-20.52%)	25.73±5.36 (-40.63%)	29.90±6.07 (+24.32%)
B. purpurea	Raw	311.31±3.65	190.09±11.33	181.32±11.53	66.77±2.41	68.09±4.26
	Boiled	289.55±1.78 (-6.99%)	86.72±3.44 (-54.38%)	116.23±5.34 (-35.90%)	49.21±1.35 (-26.30%)	53.31±2.38 (-21.71%)
	Microwave cooking	322.65±3.32 (+3.64%)	118.74±6.23 (-37.53%)	148.24±4.56 (-18.24%)	54.81±3.55 (-17.91%)	71.98±3.08 (+5.72%)
D. pentagyna	Raw	46.67±1.23	55.36±3.85	39.91±4.13	9.04±0.85	15.45±5.17
	Boiled	34.88±2.16 (-25.26%)	33.17±2.44 (-40.09%)	25.35±3.26 (-36.50%)	6.76±0.34 (-25.23%)	14.05±3.35 (-9.06 %)
	Microwave cooking	41.34±3.32 (-11.41%)	41.52±4.56 (-25.00%)	31.83±2.84 (-20.25%)	12.33±1.08 (+36.34%)	16.13±2.64 (+16.13%)
D. esculentum	Raw	112.58±2.24	211.53±3.26	65.87±3.87	16.18±3.07	21.38±5.26
	Boiled	98.49±2.08 (-12.51%)	117.72±5.24 (-44.35%)	43.70±2.38 (-33.66%)	11.67±2.32 (-27.85%)	13.68±2.19 (-36.03%
	Microwave cooking	118.46±3.22 (+5.23%)	189.45±12.45 (-10.44%)	55.34±5.12 (-15.99%)	19.66±5.25 (+21.56%)	24.78±4.38 (+15.91%)
E. latifolia	Raw	89.09±2.37	22.08±1.85	80.80±7.26	30.48±4.06	48.93±2.09
	Boiled	72.55±3.34 (-18.56%)	8.76±1.19 (-60.32%)	60.90±2.35 (-24.62%)	22.16±2.19 (-27.31%)	38.37±1.96 (-21.59%)
	Microwave cooking	81.34±3.44 (-8.70%)	14.34±2.45 (-35.05%)	69.83±4.78 (-13.57%)	33.87±3.47 (+11.11%)	51.76±3.05 (-5.78%)
E. pyriformis	Raw	103.99±3.11	28.03±2.18	71.94±2.77	51.49±3.16	60.29±3.36
	Boiled	97.45±2.89 (-6.29%)	10.24±3.44 (-63.46%)	52.33±4.32 (-27.27%)	36.10±8.17 (-29.88%)	47.13±2.29 (-21.83%)
	Microwave cooking	117.88±3.32 (+13.36%)	31.56±4.84 (+12.61%)	63.84±2.88 (-11.27%)	42.34±4.76 (-17.77%)	69.92±5.16 (+15.97%)
F. cymosum	Raw	115.35±2.87	190.37±12.68	76.46±2.55	45.25±5.09	68.36±8.15
	Boiled	101.44±3.09 (-12.06%)	105.67±6.29 (-44.49%)	47.17±5.28 (-38.31%)	31.49±3.27 (-30.42%)	53.22±4.16 (-22.15%)
	Microwave cooking	126.77±4.59 (+9.89%)	151.36±11.68 (-20.49%)	64.40±4.21 (-15.77%)	38.94±2.74 (-13.95%)	79.36±1.62 (+16.09%)
Range of Decrease /Increase in %	Boiled	Loss (2.96-25.26)	Loss (16.82-63.43)	Loss (17.90-46.71)	Loss (25.23-30.80)	Loss (9.06-36.03)
Range of Decrease /Increase in %	Microwave cooking	Decrease (6.92-11.41) Increase (2.11-13.36	Decrease (10.43-37.53) Increase (12.14-13.68)	Decrease (7.50-26.56)	Decrease (6.75-17.91) Increase (11.11-36.34)	Increase (5.72-24.32)

Each value in the table was obtained by calculating the average of three experiments (n=3) and data are presented as mean ±Standard error of the mean (SEM).

Statistical analysis were carried out by Tukeys test at 95% confidence level and statistical significance were accepted at the $p<0.05$ level. The negative value within bracket indicates percentage decrease and positive value within bracket indicates the percentage increase of the test parameters.

Microwave cooking led to an increase in the total phenolic content of *C. indica* by 2.12%, *F. vestita* by 4.41%, *D. esculentum* by 5.23%, *E. pyriformis* by 13.36%, and *F. cymosum* by 9.90%. In contrast, boiling treatment reduced the total phenolic content in all studied plants, with decreases ranging from 2.96% to 25.66%. Microwave cooking, while also causing some reduction in total phenolic content, had a lesser impact, with reductions of up to 11.41% (fig. 1).

Unlike most plants, which exhibited a significant reduction in total phenolic content (TPC) upon boiling, *C. indica* retained a relatively stable TPC. This suggests the presence of thermally stable phenolic compounds or protective structural features within its tissues that may limit leaching or degradation during heat treatment. Additionally, its phenolic profile may include compounds that are less susceptible to thermal breakdown or more readily bound to the plant matrix, reducing solubility in boiling water.

These findings warrant further investigation into the specific phenolic constituents of *C. indica* and their behavior under thermal processing. Understanding these mechanisms could provide valuable insights into optimizing cooking methods for phenolic retention in other plant species.

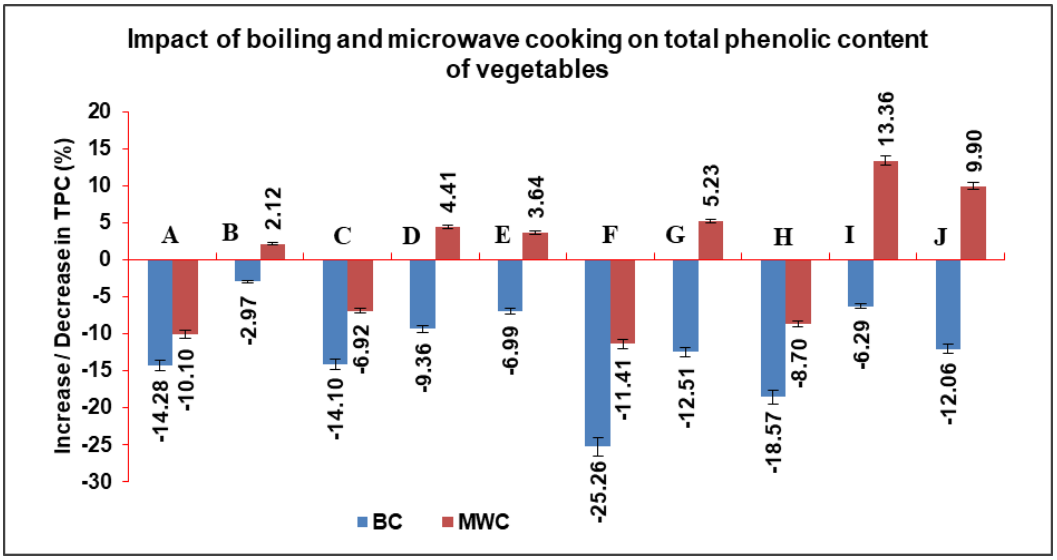

Fig. 1: Total phenolic content in wild edible plants and effect of cooking

BC: Boiled cooking, MWC: Microwaved cooking

value are expressed as mean (n=3), negative values in lowercase letters indicate a percentage decrease in total phenolic content (TPC) compared to raw samples, while positive values in uppercase letters indicate a relative percentage increase in TPC after cooking

Plant codes: A: *M. laxiflora*, B: *C. indica*, C: *D. indica*, D: *F. vestita*, E: *B. purpurea*, F: *D. pentagyna*, G: *D. esculentum*, H: *E. latifolia*, I: *E. pyriformis*, J: *F. cymosum*

Among the wild edible plants studied, *D. esculentum* had the highest total flavonoid content at 211.53 mg RE/100g, followed by *F. cymosum* with 190.37 mg RE/100g, *B. purpurea* with 190.09 mg RE/100g, and *C. indica* with 118.84 mg RE/100g (table 1). Microwave cooking was found to increase the flavonoid content in *M. laxiflora* by 12.14%, *D. indica* by 13.68%, and *E. pyriformis* by 12.61%. Boiling reduced the flavonoid content in the investigated plants by 16.82% to 63.43%, whereas microwave cooking resulted in a lesser reduction, with decreases ranging from 10.43% to 37.53% (fig. 2).

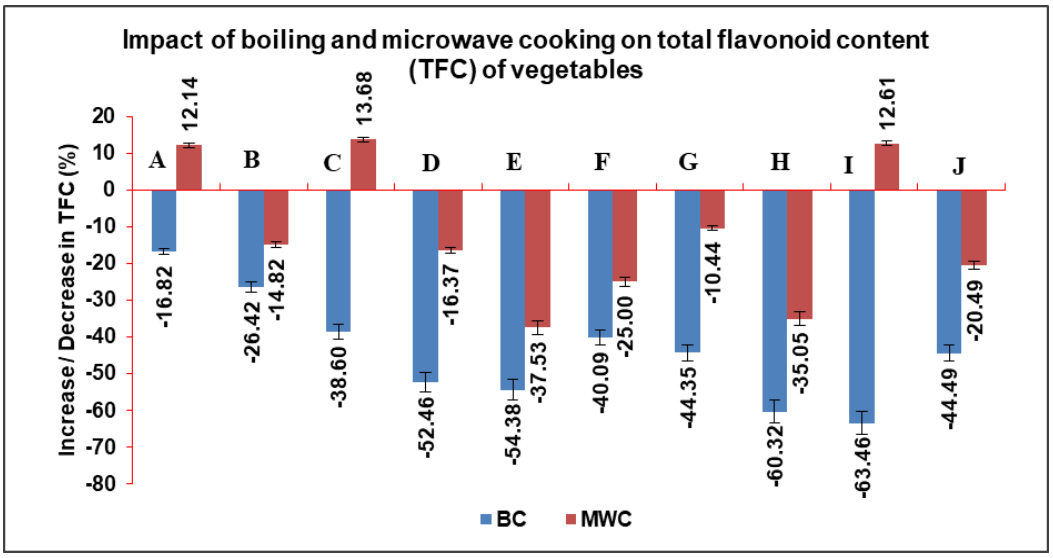

Fig. 2: Total flavonoid content in wild edible plants and effect of cooking

BC: Boiled cooking, MWC: Microwaved cooking

Value are expressed as mean (n=3), negative values in lowercase letters indicate a percentage decrease in total flavonoid content (TFC) compared to raw samples, while positive values in uppercase letters indicate a relative percentage increase in TFC after cooking

Plant codes: A: *M. laxiflora*, B: *C. indica*, C: *D. indica*, D: *F. vestita*, E: *B. purpurea*, F: *D. pentagyna*, G: *D. esculentum*, H: *E. latifolia*, I: *E. pyriformis*, J: *F. cymosum*

Our results demonstrated a significant increase ($p<0.05$) in total phenolics and flavonoids with microwave cooking. This enhancement may be attributed to the microwave treatment's ability to break down plant cell walls, which increases the extractability of polyphenols. Consequently, bound polyphenols are more readily released in the microwaved samples compared to their fresh counterparts.

The effects of different cooking methods, such as pressure cooking, microwaving, baking, griddling, or deep frying, on antioxidant activity or scavenging capacity vary significantly. These variations are influenced by several factors, including the type of vegetable, the bioavailability of phenolic compounds, the manner in which the vegetables are cut, and the specific assay system used to measure antioxidant activity. Each cooking method can alter the structure and availability of bioactive compounds differently, affecting the overall antioxidant potential of the vegetables [18-20].

The reducing power (RP) of both raw and cooked vegetables was assessed and expressed as Ascorbic Acid Equivalent (AAE), as shown in table 1. Among the wild edible plants studied, *B. purpurea* exhibited the highest reducing power at 181.32 mg AAE/100g, while *D. pentagyna* had the lowest, with 39.91 mg AAE/100g. Microwave cooking was found to decrease the reducing power by 7.50% to 26.56%, whereas boiling reduced it by 17.90% to 46.71% (fig. 3).

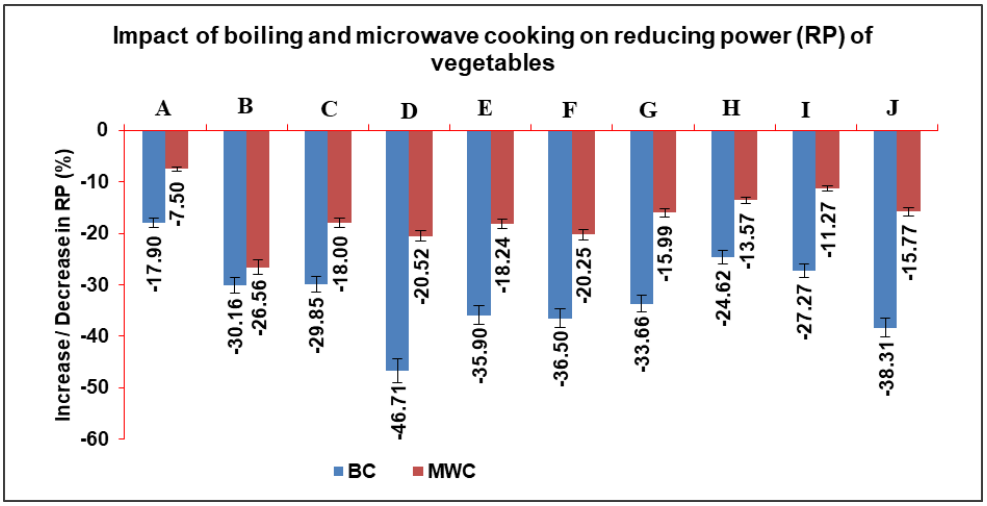

Fig. 3: Reducing power of wild edible plants and effect of cooking

BC: Boiled cooking, MWC: Microwaved cooking

value are expressed as mean (n=3), negative values in lowercase letters indicate a percentage decrease in reducing power compared to raw samples, after cooking

Plant codes: A: *M. laxiflora*, B: *C. indica*, C: *D. indica*, D: *F. vestita*, E: *B. purpurea*, F: *D. pentagyna*, G: *D. esculentum*, H: *E. latifolia*, I: *E. pyriformis*, J: *F. cymosum*

Boiling may decrease the reducing power by reducing the ascorbic acid content, which is sensitive to heat and water-soluble. In contrast, microwave cooking tends to preserve the active components in the vegetables due to shorter cooking times and reduced exposure to water. Our results generally align with this observation. Vegetables cooked in the microwave typically retained a higher reducing power compared to those boiled. This is because microwave heating is less likely to cause the release or degradation of ascorbic acid and other antioxidants from the cooked tissue, making it a preferable method for preserving these beneficial compounds [20].

Boiling or pressure cooking can lead to lixiviation, which significantly reduces the concentration of total phenolics and carotenoids by 49% and 64%, respectively [21]. This reduction occurs because phenolic compounds leach into the cooking water and complex with proteins, diminishing their antioxidant activity [22, 23]. Additionally, phenolic acids are often concentrated in the outer layers of vegetables, which are highly exposed to water during cooking. This exposure further contributes to the loss of antioxidant properties in these vegetables [24].

Conversely, microwave heating tends to preserve the active components within the vegetables. This preservation is due to the reduced cooking time and minimal use of water, which limits the leaching of phenolic compounds and other antioxidants. Our results support this observation, showing that vegetables cooked in the microwave generally exhibited higher antioxidant activity compared to those boiled. This finding is consistent with the understanding that microwave cooking, along with other methods such as griddling and baking, is less likely to stimulate the release of ascorbic acid and other antioxidants from the cooked tissue. As a result, these cooking methods are more effective at retaining the beneficial compounds in vegetables, compared to boiling, which leads to greater nutrient losses due to lixiviation [20].

According to the DPPH radical scavenging method, the antioxidant activity of fresh wild vegetables was ranked in the following order: *C. indica>B. purpurea>D. indica>E. pyriformis>F. cymosum>E. latifolia>M. laxiflora>F. vestita>D. esculentum>D. pentagyna* (see table 1). Among these vegetables, C. indica exhibited the highest DPPH radical scavenging activity with an inhibition rate of 93.06%, while *D. pentagyna* had the lowest activity with only 9.04%.

Microwave cooking significantly ($p<0.05$) enhanced the DPPH radical scavenging activity of several vegetables compared to their fresh counterparts. Increases were observed in *M. laxiflora* (21.06%), *F. vestita* (40.63%), *D. pentagyna* (36.34%), *D. esculentum* (21.56%), and *E. latifolia* (11.11%). This improvement can be attributed to the microwave cooking process, which potentially enhances the extractability and bioavailability of antioxidant compounds by breaking down cellular structures and reducing the loss of antioxidants through leaching.

In contrast, boiling reduced the DPPH radical scavenging activity of the vegetables by 25.23% to 30.80%. This decrease is likely due to

the loss of antioxidant compounds into the cooking water and the degradation of sensitive antioxidants under prolonged heat exposure. Microwave cooking, while also leading to some reduction in radical scavenging activity, caused a lesser decrease, ranging from 6.75% to 17.91% (fig. 4). The milder impact of microwave cooking on antioxidant activity is due to its shorter cooking time and reduced use of water, which help retain more of the antioxidants in the vegetable tissues.

Overall, microwave cooking appears to be a more effective method for preserving the antioxidant properties of vegetables compared to boiling, which can significantly diminish their radical scavenging activity.

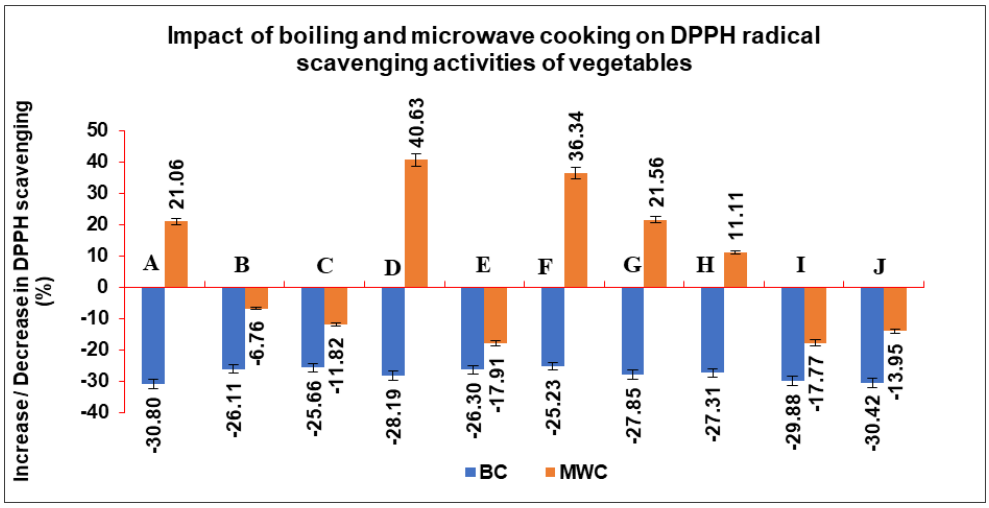

Fig. 4: DPPH radical scavenging activities of wild edible plants and effect of cooking

BC: Boiled cooking, MWC: Microwaved cooking

value are expressed as mean (n=3), negative values in lowercase letters indicate a percentage decrease in DPPH radical scavenging compared to raw samples, while positive values in uppercase letters indicate a relative percentage increase in radical scavenging after cooking

Plant codes: A: *M. laxiflora*, B: *C. indica*, C: *D. indica*, D: *F. vestita*, E: *B. purpurea*, F: *D. pentagyna*, G: *D. esculentum*, H: *E. latifolia*, I: *E. pyriformis*, J: *F. cymosum*

The antioxidant activity of wild vegetables, as assessed by the ABTS radical scavenging method, was ranked in the following order: *C. indica*>*F. cymosum*>*B. purpurea*>*E. pyriformis*>*D. indica*>*E. latifolia*>*M. laxiflora*>*F. vestita*>*D. esculentum*>*D. pentagyna* (see table 1). Among these vegetables, *C. indica* demonstrated the highest ABTS radical scavenging activity, with an inhibition rate of 82.11%, while *D. pentagyna* exhibited the lowest activity at 15.45%.

Boiling significantly reduced the ABTS radical scavenging activity of the vegetables, with decreases ranging from 9.06% to 36.03%. This reduction is likely due to the loss of antioxidant compounds into the cooking water and the thermal degradation of sensitive antioxidants. The prolonged exposure to high temperatures and water during boiling can result in substantial nutrient loss and diminished antioxidant capacity.

In contrast, microwave cooking led to a significant ($p<0.05$) increase in ABTS radical scavenging activity for all vegetables tested, with improvements ranging from 5.72% to 24.32% (fig. 5). The enhancement in antioxidant activity observed with microwave cooking can be attributed to its ability to preserve antioxidant compounds better than boiling. Microwave cooking uses shorter cooking times and minimal water, which helps to retain more of the antioxidants within the vegetable tissues. The increased antioxidant activity in microwaved vegetables suggests that this cooking method is more effective at maintaining the bioavailability of antioxidants compared to boiling.

Overall, microwave cooking not only helps to preserve but can also enhance the antioxidant properties of vegetables, whereas boiling tends to reduce these beneficial compounds.

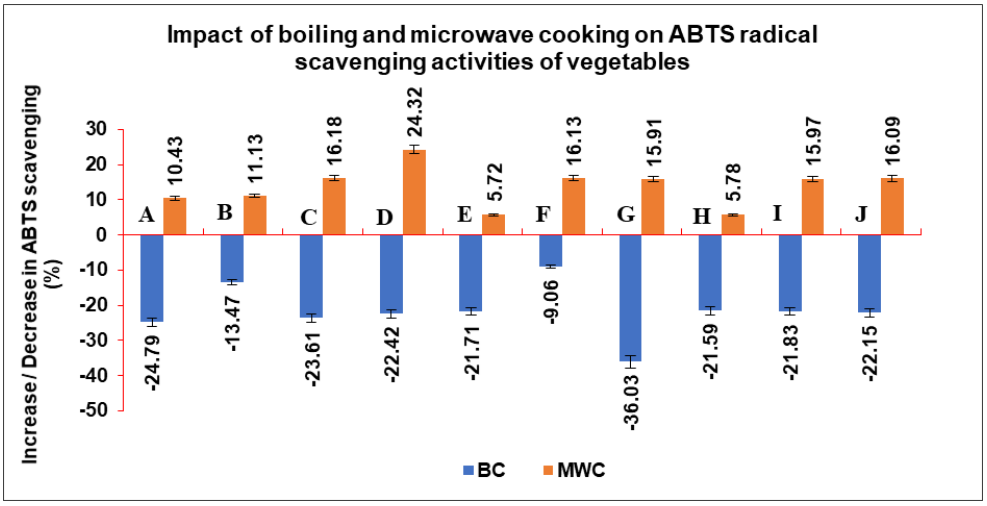

Fig. 5: ABTS radical scavenging activities of wild edible plants and effect of cooking

BC: Boiled cooking, MWC: Microwaved cooking

Value are expressed as mean (n=3), negative values in lowercase letters indicate a percentage decrease in ABTS radical scavenging compared to raw samples, while positive values in uppercase letters indicate a relative percentage increase in radical scavenging after cooking

Plant codes: A: *M. laxiflora*, B: *C. indica*, C: *D. indica*, D: *F. vestita*, E: *B. purpurea*, F: *D. pentagyna*, G: *D. esculentum*, H: *E. latifolia*, I: *E. pyriformis*, J: *F. cymosum*

The study revealed a statistically significant variation in the total antioxidant activity of edible plants when comparing raw to cooked samples. This observation aligns with findings from other research focusing on antioxidants in raw versus cooked green leafy vegetables. Similar studies have consistently demonstrated that cooking methods can substantially alter the antioxidant properties of vegetables. For instance, the impact of cooking on antioxidants often varies depending on the method used, boiling, steaming, microwaving, or frying can each differently affect the stability and bioavailability of antioxidant compounds. Boiling and pressure cooking, while effective for some types of food preparation, are known to cause significant nutrient loss due to leaching of antioxidants into the cooking water and the thermal degradation of sensitive compounds. Conversely, methods such as microwave cooking or steaming tend to preserve antioxidants better due to shorter cooking times and reduced use of water. The variation in antioxidant activity observed from raw to cooked states underscores the importance of choosing appropriate cooking methods to maximize the health benefits of vegetables. The statistically significant changes noted in our study reinforce the need to consider cooking techniques when evaluating the nutritional quality of vegetables. This aligns with previous research, which has highlighted the complex interplay between cooking methods and antioxidant levels, emphasizing that while cooking can enhance the bioavailability of certain nutrients, it can also lead to losses in others. The overall impact on antioxidant activity thus depends on both the specific vegetable and the cooking method employed [25, 26].

The extent of antioxidant activity loss in vegetables is influenced by both the surface area exposed and the duration of cooking. Generally, longer cooking times lead to greater reductions in antioxidant levels. Boiling, in particular, is known to diminish total antioxidant activity more significantly compared to microwave cooking. This reduction is largely due to the leaching of antioxidants into the boiling water, where they are lost from the vegetable matrix [25].

In contrast, microwave cooking has been reported to either preserve or enhance the antioxidant activity of vegetables. This may be because microwave cooking reduces the pro-oxidant activity associated with enzymes like peroxidases, which are often inactivated during the process. Additionally, microwave cooking can lead to the formation of new antioxidant compounds, such as those produced through Maillard reactions, which contribute to the overall antioxidant potential of the vegetables [27, 28].

Several studies support these findings, indicating that microwave cooking can either maintain or improve the antioxidant properties of vegetables. This enhancement is thought to result from the stabilization of existing antioxidants and the potential creation of novel antioxidant compounds. The improvements observed with microwave cooking highlight its advantages over other methods, such as boiling, which can result in substantial losses of antioxidant activity due to the extended exposure to high temperatures and water.

Overall, the choice of cooking method plays a crucial role in determining the final antioxidant content of vegetables. Microwave cooking proves to be a highly efficient method for maintaining or boosting the antioxidant potential of vegetables, in contrast to boiling, which significantly diminishes it due to leaching and heat-induced degradation.

The common perception that raw vegetables are the healthiest form is widely held. However, given that cooking is the predominant method of vegetable preparation in India, it is important to identify cooking techniques that best preserve their nutritional and health-promoting properties.

The current study provides valuable insights into this area, revealing that microwave cooking is particularly effective in enhancing the antioxidant activity of vegetables. Specifically, microwave cooking has been shown to increase the levels of phenolics and flavonoids, which are key compounds responsible for the antioxidant properties of vegetables.

Compared to other cooking methods, such as boiling, steaming, or frying, microwave cooking demonstrates a superior ability to preserve and even enhance these beneficial compounds. This is primarily due to the reduced cooking time and minimal use of water, which limit the leaching and degradation of antioxidants.

Understanding the impact of different cooking techniques on the nutritional quality of vegetables is essential for maximizing their health benefits. The findings of this study underscore the effectiveness of microwave cooking in retaining and boosting the antioxidant activity of green leafy and other vegetables, highlighting its advantages over more traditional methods. This insight can help guide dietary practices to ensure that the nutritional value of vegetables is preserved during preparation.

CONCLUSION

The study demonstrated that *Castanopsis indica* uniquely maintained its high radical-scavenging capacity across all cooking methods. Among the techniques evaluated, microwave cooking was the most effective in enhancing antioxidant attributes such as total phenolic and flavonoid content, reducing power, and radical scavenging activity. This efficiency is likely due to its shorter cooking duration and limited water usage, which help preserve heat-sensitive bioactive compounds. In contrast, boiling caused substantial reductions in antioxidant levels, primarily due to leaching and thermal degradation. Overall, the findings underscore microwave cooking as a superior method for retaining the nutritional and antioxidant qualities of vegetables and offer important insights for optimizing food preparation to support health benefits.

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AUTHORS CONTRIBUTIONS

Tapan Seal conceived and designed the study, and prepared the manuscript. Tapan Seal and Basundhara Pillai jointly conducted the experiments and contributed to data collection and analysis

CONFLICT OF INTERESTS

We state unequivocally that we have no competing interests

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