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Brinjal, turkey berry, and winged bean extracts: Total phenolic content and antioxidant activity

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Abstract:
Despite the known impact of cooking on the food's nutritional value, the variation in bioavailability and bioaccessibility of bioactive compounds after digestion remains inadequately understood. This study aimed to compare the effect of different cooking methods on the total phenolic content and antioxidant activity of bioaccessible and bioavailable extracts of brinjal (*Solanum melongena* L.), turkey berry (*Solanum torvum* L.), and winged bean (*Psophocarpus tetragonolobus* L.).
Each vegetable was cooked by six methods using different combinations of coconut oil, coconut milk, and spices. The cooked vegetables were digested in vitro to evaluate their bioaccessible and bioavailable total phenolic content and antioxidant activity. The total phenolic content was determined by the Folin Ciocalteu method. Free radical scavenging activity, total antioxidant capacity, and reducing power were evaluated by the DPPH, ABTS, and FRAP assays, respectively.
All the cooking methods significantly increased the total phenolic content and antioxidant activity of the extracts compared to their raw forms. The vegetables cooked with oil, milk, and spices generally showed higher total phenolics and antioxidant activity than those cooked by the other methods. We found a strong positive correlation between the total phenolic content and various antioxidant parameters. The highest bioaccessibility index for phenolic compounds was registered in the brinjal extract cooked with oil and in the turkey berry and winged bean extracts cooked with oil, milk, and spices. Different cooking methods exhibited varying effects on the antioxidant activity of bioaccessible compounds. In bioavailable extracts, variability was observed for the total phenolic content and antioxidant activity among different cooking methods for brinjal, turkey berry, and winged bean.
The ABTS and FRAP assays showed the highest total phenolic content and antioxidant activity in all the vegetables cooked with coconut oil, milk, and spices.

Keywords: *Solanum melongena* L., *Solanum torvum* L., *Psophocarpus tetragonolobus* L., *in vitro* digestion, bioaccessibility, antioxidants, bioactive compounds, bioavailability, cooking methods

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INTRODUCTION

Vegetables exhibit multiple health benefits closely related to significant amounts of bioactive compounds in them. These include phenolic compounds, flavonoids, lignin, resveratrol, tannins, and alkaloids with antioxidant properties. Antioxidants are substances with an ability to inhibit or delay oxidative damage of nucleic acids, lipids, and proteins. Oxidative breakdown products such as reactive oxygen, nitrogen, and sulphur species link with chronic diseases. According to numerous studies, antioxidant-active compounds decrease the risk of various diseases, including cancer, cardiovascular disease, inflammation, diabetes, ulcers, osteoporosis, Alzheimer's disease, rheumatoid arthritis, cataracts, and age-related disorders [1].

Brinjal (*Solanum melongena* L.), originated from Asia, is one of the most widespread vegetables consumed around the world. Brinjal has a high free radical

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scavenging capacity and is popular among consumers and researchers. Its high antioxidant activity is due to the presence of phenolic compounds, including delphinidin in the brinjal peel and chlorogenic acid in the flesh. Further, brinjal peels contain important bioactive compounds such as anthocyanins and flavonoids. The phenolic acids present in brinjal are classified into two classes: hydroxybenzoic acids and hydroxycinnamic acids. Caffeic and ferulic acids are the most common hydroxycinnamic acids in the plant kingdom, while *p*-coumaric, sinapic, and cinnamic acids are less common [2].

Turkey berry (*Solanum torvum* L.) is a vegetable commonly grown in all tropic countries. Originating from Central and South America, it is a member of the *Solanaceae* family. Turkey berry is not only used as a food product, but also in traditional medicine in Asia and Africa to prevent and cure a range of diseases. Turkey berry fruits contain high concentrations of various polyphenolic compounds, phenols, flavonoids, and tannins. These bioactive compounds account for turkey berry's high antioxidant activity [3].

Winged bean (*Psophocarpus tetragonolobus* L.) is a typical food crop and an underexploited food source for the tropics. It belongs to the *Fabaceae* family. Winged beans contain bioactive compounds with potential antioxidants, including vitamin C and E, polyphenols, and flavonoids. Studies have demonstrated anti-inflammatory, antimicrobial, anticarcinogenic, antitumoral, antimutagenic, anti-allergic, anti-aggregate, and anti-ischemic properties of winged beans [4].

Vegetables are generally cooked by different cooking processes before consumption. The cooking methods significantly impact their total phenolic content and antioxidant activity. Changes in bioactive concentrations and antioxidant capacities depend on the species and the method of cooking. The total phenolic content and antioxidant activity may vary between raw and cooked vegetables [5].

Health benefits of phenolics greatly depend on their bioaccessibility and bioavailability in the digestive tract and circulatory system. Bioaccessibility refers to a fraction of a compound released from the food matrix during digestion that becomes available for absorption in the gastrointestinal tract. Bioavailability is defined as a fraction of an ingested compound that reaches the circulatory system and is utilized by the body. Bioaccessibility and bioavailability of phenolic compounds are studied using *in vitro* (stimulated digestion) and *in vivo* models (animal model or human clinical trials). *In vitro* models are quick, technically simple, and inexpensive. They allow for screening numerous samples to study the efficiency of each digestion, absorption or transport mechanism [6, 7].

In this study, we aimed to compare the effect of different cooking methods on the total phenolic content and antioxidant activity of bioaccessible and bioavailable extracts of brinjal, turkey berry, and winged bean using *in vitro* models.

STUDY OBJECTS AND METHODS

Brinjal, turkey berry, and winged bean samples were collected from local markets. The vegetables were cleaned, washed, and cut into small slices separately. From each vegetable, seven portions of slices (30 g/portion) were weighed and separated. They were used to prepare seven different samples of each vegetable, namely raw, cooked with oil, cooked with milk, cooked with oil and milk, cooked with oil and spices, cooked with milk and spices, as well as cooked with oil, milk, and spices. The coconut oil, coconut milk, and spice mixtures used in the study were of the same brand.

Preparation of samples. ***Preparation of raw extracts.*** Thirty-gram portions of raw slices of each vegetable were individually blended with a small volume of distilled water and transferred to a clean cotton cloth separately. The extracts were collected by squeezing the samples in the cotton cloth. Each extract was topped up to 100 mL using distilled water. Finally, the extracts were collected into separate containers, labelled as R (raw) for respective vegetables, and stored at –18°C for further analysis.

Cooking with coconut oil. Thirty-gram portions of raw slices of each vegetable were stir-fried separately with 5 mL of coconut oil using an induction cooker at 80°C for 3 min. Mixtures of 0.50 g of chili powder, 1 g curry powder, 0.25 g turmeric powder, and 0.50 g salt were added to each portion. After that, the samples were cooked at 80°C for 6 min. The cooked samples were blended and transferred to a clean cotton cloth separately. The extracts were collected by squeezing the samples in the cotton cloth. Each extract was topped up to 100 mL using distilled water. Finally, the extracts of each vegetable were collected into containers, labelled as COS (cooked with oil and spices) for respective vegetables, and stored at –18°C for further analysis.

The same procedure was followed to cook 30 g portions of each vegetable without using the spices. The prepared samples were labelled as CO (cooked with oil) for respective vegetables and stored at –18°C for further analysis.

Cooking with coconut milk. Thirty-gram portions of raw slices of each vegetable were cooked separately with 10 mL of coconut milk for 3 min at 80°C. Mixtures of 0.50 g of chili powder, 1 g curry powder, 0.25 g turmeric powder, and 0.50 g salt were added into each portion. Then, 40 mL of coconut milk was added into all three preparations. The samples were mixed well and cooked at 80°C for 8 min. The cooked samples were blended and transferred to a clean cotton cloth separately. The extracts were collected by squeezing the samples. Each extract was topped up to 100 mL using distilled water. Finally, the extracts were collected into containers separately, labelled as CMS (cooked with milk and spices) for respective vegetables, and stored at –18°C for further analysis.

The same procedure was followed to cook 30 g portions of each vegetable without using the spices. The prepared samples were labelled as CM (cooked with

milk) for respective vegetables, and stored at –18°C for further analysis.

Cooking with coconut oil and coconut milk. Thirty-gram portions of raw slices of each vegetable were stir-fried with 5 mL of coconut oil separately using an induction cooker at 80°C for 3 min. Mixtures of 0.50 g of chili powder, 1 g curry powder, 0.25 g turmeric powder, and 0.50 g salt were added separately into each portion. Then, 50 mL of coconut milk was added into all three preparations and cooked at 80°C for 8 min. The cooked samples were blended and transferred to a clean cotton cloth separately. The extracts were collected by squeezing the samples. Each extract was topped up to 100 mL using distilled water. Finally, the extracts of each vegetable were collected into containers separately, labelled as COMS (cooked with oil, milk, and spices) for respective vegetables, and stored at –18°C for further analysis.

The same procedure was followed to cook 30 g portions of each vegetable without using the spices. The prepared samples were labelled as COM (cooked with oil and milk) for respective vegetables, and stored at –18°C for further analysis.

***In vitro* digestion process.** The below mentioned *in vitro* digestion process was carried out for differently cooked samples of brinjal, turkey berry and winged bean separately.

Oral phase. *In vitro* digestion was performed according to the method described by Minekus *et al.* [8] with some modifications. For this, 3-g portions of each cooked sample were mixed with 2.1 mL of a simulated salivary fluid (SSF) solution, partially blended with a blender, and transferred into a clean beaker. Subsequently, we added 0.3 mL of α-amylase of 1500 U/mL made up in the SSF electrolyte stock solution. Finally, 15 µL of 0.3 M $CaCl_2$ and 585 µL of water were added and mixed well. The beaker was kept in the heating water bath for 2 min at 37°C. The mixture obtained in this process is known as an oral bolus.

Gastric phase. To produce gastric chime, 6.00 mL of the oral bolus was mixed with 4.50 mL of a simulated gastric fluid (SGF), 0.96 mL of a porcine pepsin stock solution of 25000 U/mL made up in the SGF electrolyte stock solution, and 3 µL of 0.3 M $CaCl_2$. Then, 0.12 mL of 1 M HCl was added to obtain a pH value of 3.0 in the final mixture. The mixture was made up to 12.00 mL using distilled water. The beaker was kept in a shaking water bath for 2 h at 37°C.

Intestinal phase. The intestinal digestion was conducted in a 15 cm long dialysis tube. One end of the dialysis tube was closed using a twine thread and 12.00 mL of gastric chyme was added into it. Then, 6.6 mL of a simulated intestinal fluid (SIF) electrolyte was added and mixed well. After that, we added and mixed 3.00 mL of a pancreatin solution of 800 U/mL made up in the SIF electrolyte stock solution based on trypsin activity, 1.5 mL of a bile solution, and 24 µL of 0.3 M $CaCl_2$. Subsequently, 0.09 mL of 1 M NaOH was added to the mixture to get a final pH value of 7.0. Finally, the mixture was made up to 24.00 mL using distilled water. The dialysis tube was placed in a 100-mL beaker with 50.00 mL of distilled water. The beaker was kept in a shaking water bath for 2 h at 37°C. The content in the tube was filtered using 1-µm filter paper and the filtrate was stored at –18°C for further bioaccessibility analysis.

The outer solution of the tube was stored at –18°C for further bioavailability analysis.

Evaluation of total phenolic content and antioxidant activity. ***Total phenolic content.*** The Folin-Ciocalteu method was used to determine the total phenolic content as described by Swain and Hillis [9] with some modifications. Each cooked and digested vegetable sample (150 µL) was mixed with 2.4 mL of distilled water and 150 µL of 0.25 N Folin-Ciocalteu's reagent and allowed to react for 3 min. Then, 300 µL of sodium carbonate was added to this mixture. The final mixture was kept in the dark for 30 min. After that, absorbance was measured at 760 nm using a spectrophotometer. Each trial was done in three replicates and gallic acid was used to create a standard curve. The total phenolic content (TPC) was calculated using the following Eq. (1):

$$\text{TPC} = \frac{\text{Amount of gallic acid, µg}}{\text{Weight of vegetable sample, g}} \quad (1)$$

The result was expressed as mg of gallic acid equivalents (GAE) in 100 g of the food sample on a fresh weight basis.

DPPH assay. The antioxidant activity was measured using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay (free radical scavenging activity) as described by Brand-Williams *et al.* [10] with some modifications. For this, 2 mL of a DPPH solution (100 µM, 99% methanol) was added to different volumes (150, 300, 450, 600, and 750 µL) of each cooked and digested vegetable extract (0.01 mg/mL concentration). The mixtures were made up to 4 mL by adding distilled water. Then, we allowed them to stand for 30 min in a dark place at room temperature. After the incubation period, the absorbance was measured at 517 nm using a spectrophotometer. The DPPH radical scavenging activity (RSA, %) was calculated using the Eq. (2):

$$\text{RSA} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100 \quad (2)$$

where A_{control} is the absorbance of the control; A_{sample} is the absorbance of a sample.

A graph was plotted [% inhibition (scavenging activity) against the concentration of samples] and 50% inhibition (IC_{50}) was obtained for the respective concentrations.

ABTS assay. The procedure explained by Re *et al.* [11] was used with some modifications. For this, 7.4 mM of ABTS radical solution and 2.6 mM potassium persulphate solution were used as the stock solution in the ABTS [2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic) acid] assay. The working solution was prepared by mixing the stock solutions equally and left to react for 12 h in the dark at room temperature. This solution was diluted by mixing 1 and 60 mL of the ABTS radical solution

and methanol, respectively. Then, 2.85 mL of the ABTS radical solution was left to react with 150 µL of an extract for 2 h in a dark place. The absorbance was read over 6 min at 734 nm using a spectrophotometer. The percentage inhibition of absorbance at 734 nm was calculated and the results were expressed as a percentage inhibition.

FRAP assay. The procedure explained by Benzie and Strain [12] was used with some modifications. For this, 300 mM of acetate buffer, 20 mM ferric chloride solution, and 10 mM 2,4,6-Tris(2-pyridyl)-s-triazine (TPTZ) solutions were prepared and mixed in a 10:1:1 ratio to prepare a ferric ion reducing antioxidant power (FRAP) reagent. The FRAP reagent was incubated at 37°C for 10 min. Then, 2.85 mL of the incubated FRAP reagent was left to react with 150 µL of a sample for 30 min in the dark. The absorbance of the colored product was measured at 593 nm using a UV-visible spectrophotometer. Trolox was used to create a calibration curve. The results were expressed as mg of Trolox equivalents in 1 g of a food sample.

Bioaccessibility and bioavailability indexes. Bioaccessibility index and bioavailability indexes were calculated using the following Eq. (3)–Eq. (6) [13, 14]:

$$\mathrm{PCBI} = \frac{\mathrm{PC_a}}{\mathrm{PC_b}} \times 100 \quad (3)$$

where PCBI is the phenolic compound bioaccessibility index, %; PC_a is the phenolic content in the bioaccessible extract; PC_b is the phenolic content in the cooked extract.

$$\mathrm{PBVI} = \frac{\mathrm{PC_a}}{\mathrm{PC_b}} \times 100 \quad (4)$$

where PBVI is the phenolic compounds bioavailability index, %; PC_a is the phenolic content in the bioavailable extract; PC_b is the phenolic content in the cooked extract.

$$\mathrm{AABI} = \frac{A_a}{A_b} \times 100 \quad (5)$$

where AABI is the antioxidant activity bioaccessibility index, %; A_a is the antioxidant activity of the bioaccessible extract; A_b is the antioxidant activity of the cooked extract.

$$\mathrm{AAVI} = \frac{A_a}{A_b} \times 100 \quad (6)$$

where AAVI is the antioxidant activity bioavailability index, %; A_a is the antioxidant activity of the bioavailable extract; A_b is the antioxidant activity of the cooked extract.

The AABI and AAVI were calculated individually for each result obtained via the DPPH, ABTS, and FRAP assays.

Statistical analysis. The data were expressed as mean ± SD (triplicate). Statistical analysis was performed using the Minitab 17 software. Statistical significance of the total phenolic content and antioxidant activity of the vegetables cooked with different methods was determined by one-way analysis of variance with Fisher's pairwise comparisons. Statistical significance of the bioaccessibility and bioavailability indexes was determined by one-way analysis of variance with a Tukey post hoc analysis. The differences were considered significant at $p < 0.05$. Pearson's correlation test was used to determine the correlation between the total phenolic content and antioxidant activity from different assays.

RESULTS AND DISCUSSION

Total phenolic content and antioxidant activity of vegetables cooked by different methods. ***Total phenolic content and antioxidant activity of raw samples.*** The tested cooking methods are common in Sri Lankan cuisines. The total phenolic content (TPC) and antioxidant activity of the raw and cooked vegetables are presented in Table 1. According to statistical analysis, the cooking methods had a significant ($p < 0.05$) effect on the TPC and antioxidant activity of brinjal, turkey berry, and winged beans. Compared to the raw vegetable extracts, the cooked vegetable extracts exhibited higher TPC and antioxidant activity, indicating the benefit of adapting Sri Lankan culinary methods. The TPC of raw brinjal used in our study reached 115.33 ± 5.25 mg GAE/100 g, lying within the range (78.3 to 125.4 mg GAE/100 g) reported by Chumyam *et al.* [15] in four eggplant cultivars.

The ABTS assay showed that the vegetables in our study had higher antioxidant activity than four cultivars of eggplant in the study by Chumyam *et al.* [15]. According to the DPPH assay, the turkey berry had higher antioxidant activity (IC_{50} value 4.71 ± 0.02%) compared to the study by Kortei *et al.* [16]. The TPC and IC_{50} values of winged beans were 147.55 ± 4.40 mg GAE/100 g and 4.28 ± 0.07 mg/mL, respectively.

Total phenolic content of cooked vegetables. There was a significant difference in the total phenolic content of brinjal and winged bean samples obtained by different cooking methods. However, the methods increased TPC values in a different order, namely COMS > CMS > COM > COS > CM > CO for brinjal and COMS > CMS > COS > COM > CM > CO for winged beans (COMS – cooked with oil, milk, and spices; CMS – cooked with milk and spices; COM – cooked with oil and milk; COS – cooked with oil and spices; CM – cooked with milk; and CO – cooked with oil). No significant difference was observed in the TPC values for turkey berry extracts between the samples cooked with oil, milk, and spices (1647.23 ± 1.15 mg GAE/100 g) and those cooked with milk and spices (1583.40 ± 2.32 mg GAE/100 g), as well as between the samples cooked with milk (1025.39 ± 1.56 mg GAE/100 g) and those cooked with oil (979.16 ± 4.72 mg GAE/100 g).

Among the cooking methods, cooking with oil showed the lowest TPC for all the vegetable extracts. Similarly, Gunathilake *et al.* [5] found that fried leafy vegetables had lower values of polyphenols, flavonoids, carotenoids, and antioxidant activity compared to boiled leafy vegetables.

Antioxidant activity by DPPH assay for cooked vegetables. The DPPH-determined antioxidant activity of cooked brinjal, turkey berry, and winged bean extracts showed significant difference between the cooking methods. Further, the turkey berry and winged bean extracts revealed the same order in accordance with the cooking methods, namely COMS > CMS > COS > CM > CO > COM, while brinjal showed a different order, COMS > CMS > COS > CO > COM > CM (COMS – cooked with oil, milk, and spices; CMS – cooked with milk and spices; COM – cooked with oil and milk; COS – cooked with oil and spices; CM – cooked with milk; and CO – cooked with oil).

Antioxidant activity by ABTS assay for cooked vegetables. The ABTS-determined antioxidant activity of differently cooked brinjal, turkey berry, and winged bean extracts showed significant difference between the cooking methods. They also revealed a different order of the methods, namely COMS > CMS > COS > COM > CO > CM for brinjal, COMS > COS > CMS > COM > CM > CO for turkey berry, and COMS > CMS > COS > COM > CM > CO for winged beans.

Antioxidant activity by FRAP assay for cooked vegetables. The FRAP-determined antioxidant activity of cooked brinjal extracts showed significant difference between the cooking methods. However, the antioxidant activity of turkey berry and winged beans revealed no significant difference in the cooking methods between the samples cooked with milk and those cooked with oil and milk, as well as between the samples cooked with oil and those cooked with oil and milk. Further, brinjal and turkey berry showed the same order in accordance with the cooking methods, namely COMS > CMS > COS > COM > CM > CO, while winged beans showed a different order, COMS > CMS > COS > CM > COM > CO.

According to the FRAP assay, the vegetable extracts showed higher antioxidant activity when cooked with spices: COMS > CMS > COS, compared to the other methods. The spices included turmeric, chili, and curry powders. Turmeric powder contains a variety of phenolic and bioactive compounds including curcumin, demethoxycurcumin, bisdemethoxycurcumin, ferulic acid, and vanillic acid [17]. Chili powder acts as an antioxidant due to the presence of metabolites with antioxidant capacities, such as capsaicinoids, ascorbic acid, vitamin E, provitamin A, carotenoids, xanthophylls, and phenolic compounds [18]. The curry powder contained coriander, cumin, fenugreek, and mustard seeds, as well as black pepper. Thus, the spices were rich in antioxidants including flavonoids, phenolic compounds, sulfur-containing compounds, tannins, alkaloids, phenolic diterpenes, and vitamins [19].

The vegetable samples cooked with oil, milk, and spices showed the highest total phenolic content and antioxidant activity determined by the DPPH, ABTS, and FRAP assays, except for the DPPH-determined antioxidant capacity of the brinjal extract. Cooking with coconut milk and coconut oil adds more types of polyphenolic and antioxidant compounds to the extract. Further, it helps in extracting both oil- and water-soluble antioxidant and polyphenolic compounds from the food matrix.

Relationship between phenolic compounds and antioxidant capacity. Table 2 depicts the correlation analysis between the total phenolic content and antioxidant capacity by DPPH, ABTS, and FRAP assays. The results showed a very strong correlation ($p < 0.05$) between the TPC and antioxidant capacity values of all the vegetable extracts, raw or cooked. This suggests that the phenolic compounds present in the extracts contributed significantly to the observed antioxidant effect and there was a significant linear relationship between the TPC and antioxidant capacity. Most plant polyphenols display significant antioxidant properties, mainly as free radical scavengers [20]. Many studies established a positive strong correlation between the TPC and antioxidant capacity [21]. The *r* values ranged from –1.00 to 1.00, showing a strong correlation between the variables, and the negative and positive values indicated an inverse and direct relationship between the variables. The TPC and DPPH (IC_{50}) values showed a negative strong relationship, with the IC_{50} value being inversely proportional to antioxidant capacity. The TPC and DPPH correlation for the brinjal and winged bean extracts was slightly less strong than that for the turkey berry extract. The TPC and ABTS correlation and the TPC and FRAP correlation for the winged bean extract were slightly stronger than those for the brinjal and turkey berry extracts.

Bioaccessibility indexes of phenolic compounds and antioxidant activity. We determined the effect of *in vitro* digestion on the total phenolic content and antioxidant capacity of the brinjal, turkey berry, and winged bean extracts cooked by different methods. Their bioaccessibility indexes are presented in Table 3.

Phenolic compound bioaccessibility index. The phenolic compound bioaccessibility index (PCBI) of the brinjal extract cooked by different methods ranged from 24.54 to 65.90%. This was in line with the results of Neto *et al.* [13], where the bioaccessibility of plant extract phenolic compounds varied from 30 to 100%. The brinjal extract cooked with coconut oil (CO) had the highest PCBI (65.90%) followed by the samples cooked with oil and milk (COM, 57.65%); milk (CM, 48.57%); oil and spices (COS, 44.50%); oil, milk, and spices (COMS, 31.38%); and milk and spices (CMS, 24.54%). Even though cooking with oil, milk, and spices and cooking with milk and spices showed higher total phenolic content (TPC) values before digestion, the PCBI for these methods were lower than for the other methods. The PCBI for turkey berry cooked by different methods varied from 13.38 to 32.51%. The turkey berry extract cooked with oil, milk, and spices showed the highest PCBI (32.51%) followed by the COS, CM, CMS, COM, and CO samples. The PCBI for winged bean ranged from 29.57 to 55.89%. The winged bean extract cooked with oil, milk, and spices showed the highest PCBI followed by the CMS, COS, CO, COM, and CM samples.

The digested samples of brinjal, turkey berry, and winged beans had lower TPC values regardless of the

Table 1 Effect of different cooking methods on total phenolic content and antioxidant capacity by DPPH, ABTS, and FRAP

Cooking methods	Brinjal				Turkey berry				Winged bean			
	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g
R	115.33 ± 5.25^{g}	5.10 ± 0.02^{a}	31.85 ± 0.03^{g}	0.91 ± 0.06^{g}	862.78 ± 2.82^{e}	4.71 ± 0.02^{a}	27.43 ± 0.12^{g}	10.08 ± 0.01^{g}	147.55 ± 4.40^{g}	4.28 ± 0.07^{a}	36.21 ± 0.10^{g}	0.50 ± 0.01^{f}
CO	140.01 ± 7.13^{f}	3.70 ± 0.03^{d}	43.47 ± 0.04^{e}	2.20 ± 0.06^{f}	979.16 ± 4.72^{d}	4.44 ± 0.02^{c}	36.30 ± 0.12^{f}	14.34 ± 0.01^{f}	184.00 ± 5.98^{f}	4.05 ± 0.04^{c}	49.66 ± 0.03^{f}	1.65 ± 0.02^{e}
CM	252.63 ± 7.64^{e}	4.77 ± 0.03^{b}	41.23 ± 0.01^{f}	2.77 ± 0.04^{e}	1025.39 ± 1.56^{d}	4.01 ± 0.01^{d}	41.73 ± 0.01^{e}	23.38 ± 0.02^{d}	242.67 ± 7.96^{e}	3.76 ± 0.03^{d}	53.23 ± 0.03^{e}	2.18 ± 0.01^{d}
COM	304.99 ± 6.67^{c}	4.26 ± 0.04^{c}	46.84 ± 0.02^{d}	2.95 ± 0.05^{d}	1278.07 ± 1.72^{b}	4.54 ± 0.01^{b}	43.30 ± 0.08^{d}	29.92 ± 0.07^{d}	295.26 ± 10.02^{d}	4.19 ± 0.03^{b}	55.62 ± 0.05^{d}	1.75 ± 0.02^{e}
COS	279.64 ± 5.17^{d}	3.53 ± 0.02^{e}	49.76 ± 0.03^{c}	8.75 ± 0.04^{c}	1202.00 ± 113.80^{c}	3.78 ± 0.01^{e}	53.81 ± 0.12^{b}	38.74 ± 0.01^{c}	322.47 ± 6.36^{c}	3.33 ± 0.02^{e}	62.92 ± 0.01^{c}	2.99 ± 0.16^{c}
CMS	564.54 ± 5.34^{b}	2.67 ± 0.02^{g}	53.23 ± 0.03^{b}	10.10 ± 0.04^{b}	1583.40 ± 2.32^{a}	2.92 ± 0.02^{f}	51.24 ± 0.10^{c}	39.73 ± 0.02^{b}	370.13 ± 13.21^{b}	3.25 ± 0.02^{f}	67.41 ± 0.03^{b}	3.62 ± 0.01^{b}
COMS	596.60 ± 4.45^{a}	2.94 ± 0.03^{f}	56.11 ± 0.05^{a}	14.30 ± 0.04^{a}	1647.23 ± 1.15^{a}	2.18 ± 0.01^{g}	57.28 ± 0.11^{a}	42.43 ± 0.01^{a}	569.20 ± 7.94^{a}	3.17 ± 0.02^{g}	76.87 ± 0.02^{a}	4.43 ± 0.04^{a}

Results were expressed as mean ± SD (n = 3). The values followed by the same letters in the same column are not significantly different ($p < 0.05$); R – raw; CO – cooked with coconut oil; CM – cooked with coconut milk; COM – cooked with coconut oil and milk; COS – cooked with coconut oil + spices; CMS – cooked with coconut milk + spices; COMS – cooked with coconut oil and milk + spices

Table 2 Correlation analysis between total phenolic content and antioxidant parameters

Assays	Brinjal		Turkey berry		Winged bean	
	r	*p*-value	*r*	*p*-value	*r*	*p*-value
TPC and DPPH	–0.798	0.032	–0.885	0.008	–0.806	0.029
TPC and ABTS	0.868	0.011	0.859	0.013	0.944	0.001
TPC and FRAP	0.897	0.006	0.902	0.005	0.928	0.003

Seven paired mean samples from each assay were used in the comparison; *r* values denote Pearson's correlation value ($p < 0.05$)

Table 3 Bioaccessibility indexes for total phenolic content and antioxidant activity

Cooking methods	Brinjal				Turkey berry				Winged bean			
	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g
CO	65.90^{a}	53.08^{d}	94.66^{f}	129.09^{b}	13.38^{f}	68.10^{b}	95.98^{e}	60.74^{b}	35.73^{d}	306.82^{b}	92.81^{a}	295.76^{d}
CM	48.57^{c}	71.41^{a}	105.21^{b}	171.48^{a}	25.34^{e}	62.36^{d}	89.82^{f}	32.72^{f}	29.57^{e}	284.85^{c}	90.96^{b}	136.70^{f}
COM	57.65^{b}	66.88^{c}	102.88^{d}	85.76^{d}	22.78^{e}	71.72^{a}	104.73^{b}	33.46^{e}	35.65^{d}	346.28^{a}	88.76^{c}	207.43^{e}
COS	44.50^{d}	53.48^{d}	106.07^{a}	77.60^{f}	25.93^{b}	64.95^{c}	96.95^{d}	52.74^{d}	39.42^{c}	277.50^{e}	86.11^{d}	375.92^{c}
CMS	24.54^{f}	47.94^{e}	103.95^{c}	98.02^{c}	24.88^{d}	50.52^{e}	110.28^{a}	55.42^{c}	47.04^{b}	273.11^{f}	78.34^{e}	533.43^{a}
COMS	31.38^{e}	68.69^{b}	97.38^{e}	82.10^{e}	32.51^{a}	39.14^{f}	103.91^{c}	75.75^{a}	55.89^{a}	278.07^{d}	74.39^{f}	376.75^{b}

The values followed by the same letters in the same column are not significantly different (Tukey's test, $p < 0.05$); CO – cooked with coconut oil; CM – cooked with coconut milk; COM – cooked with coconut oil and milk; COS – cooked with coconut oil + spices; CMS – cooked with coconut milk + spices; COMS – cooked with coconut oil and milk + spices

cooking method, compared to the TPC of the cooked samples. This may be due to the low pH in the stomach which caused a breakdown of phenolic compounds [22]. Further, each cooking method showed a significant difference in the TPC except for the winged bean extract cooked with oil or with oil and milk.

Antioxidant activity bioaccessibility index. The antioxidant activity bioaccessibility index (AABI) for the brinjal, turkey berry, and winged bean extracts cooked by different methods was based on DPPH, ABTS, and FRAP assays. The AABI < 100% indicated that the antioxidant activity became less bioaccessible, implying a loss of bioactive compounds during digestion. The AABI = 100% suggested that digestion did not significantly alter the bioaccessibility of bioactive compounds and the antioxidant capacity remained consistent before and after digestion. The AABI > 100% indicated that digestion improved the bioaccessibility through the release of bioactive compounds by breaking down the food matrix.

According to the DPPH assay, brinjal cooked with coconut milk and spices exhibited high antioxidant activity, while the digested brinjal extract cooked with milk showed a high AABI (71.41%). Further, all the methods of cooking brinjal revealed a significant difference, except for cooking with oil (53.08%) and cooking with oil and spices (40.25%). The AABI for the turkey berry extract varied from 39.14 to 71.72%. Even though cooking turkey berry with oil, milk, and spices showed the highest antioxidant capacity before digestion, it had a lower AABI (39.14%). This may be due to the breakdown of bioactive compounds during the digestion process [23]. The AABI for winged beans exceeded 100% for all the cooking methods. This indicated that the digestion process enhanced the release of bioactive compounds in the cooked winged beans.

The ABTS assay showed AABI values of over 100% for the brinjal extracts CM, COM, COS, and CMS, as well as for the turkey berry extracts cooked with COM, CMS, and COMS. This indicated that digestion improved the bioaccessibility through the release of bioactive compounds by breaking down the food matrix and making compounds more accessible.

According to the FRAP assay, AABI values of over 100% were registered in the brinjal extracts CO and CM, as well as in the winged bean extracts cooked by all the tested methods. However, the turkey berry extracts cooked by different methods showed AABI values of below 100%, with the sample COMS having the highest AABI value of 75.75%.

The selected vegetables cooked by different methods showed differences in the PCBI and AABI values. The differences in bioaccessibility could be due to several factors, such as possible interactions with other food components, the chemical state of the compounds, and their release from the food matrix [22].

Bioavailability indexes of phenolic compounds and antioxidant activity. *In vitro* bioavailability indexes for phenolic compounds and antioxidant activity are presented in Table 4.

Phenolic compound bioavailability index. The phenolic compound bioavailability index (PBVI) of the brinjal extracts ranged from 32.77 to 53.71%. The brinjal extract CO showed the highest phenolic compound bioaccessibility index (PCBI) and PBVI, while that COS had the lowest PCBI and PBVI. The turkey berry extract COMS exhibited the highest PCBI and PBVI. The winged bean extract CMS showed the highest PBVI (53.78%), while that COMS exhibited the lowest PBVI (37.62%), compared to the other cooking methods. The three vegetables cooked by different methods showed significant differences in total phenols, except for the winged beans CM and COM.

Antioxidant activity bioavailability index. The brinjal extract CM showed the highest antioxidant activity bioavailability index **(**AAVI) according to the DPPH (50.53%) and ABTS (55.74%) assays, while that cooked with coconut oil revealed the highest index according to the FRAP assay (149.09%). The turkey berry extracts cooked by different methods exhibited different antioxi-

Table 4 Bioavailability indexes for total phenolic content and antioxidant activity

Cooking methods	Brinjal				Turkey berry				Winged bean			
	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g	TPC, mg GAE/100 g	DPPH, IC_{50} mg/mL	ABTS, %	FRAP, mg TE/g
CO	53.71^{a}	35.51^{e}	51.35^{b}	149.09^{a}	14.26^{e}	50.80^{b}	54.16^{d}	27.62^{c}	46.23^{c}	32.43^{e}	49.25^{c}	211.52^{a}
CM	32.77^{b}	50.53^{a}	55.74^{a}	114.80^{b}	13.76^{f}	45.41^{d}	48.21^{f}	35.80^{a}	41.75^{d}	38.56^{a}	51.12^{b}	157.34^{c}
COM	27.56^{d}	45.46^{b}	49.98^{d}	107.12^{c}	16.28^{d}	54.31^{a}	51.25^{e}	29.14^{b}	41.81^{d}	38.51^{a}	88.78^{a}	188.00^{b}
COS	30.54^{c}	40.25^{d}	50.60^{c}	39.43^{d}	19.30^{c}	48.46^{c}	55.29^{c}	23.00^{d}	48.42^{b}	36.20^{d}	46.41^{d}	113.71^{d}
CMS	22.93^{f}	33.50^{f}	49.84^{d}	37.43^{e}	19.78^{b}	38.07^{e}	59.04^{a}	22.43^{e}	53.78^{a}	37.44^{b}	42.52e	100.28^{e}
COMS	26.72^{e}	44.41^{c}	47.82^{c}	27.34^{f}	28.25^{a}	28.24^{f}	56.06^{b}	21.61^{f}	37.62^{e}	36.65^{c}	40.55f	80.36^{f}

The values followed by the same letters in the same column are not significantly different (Tukey's test, $p < 0.05$); CO – cooked with coconut oil; CM – cooked with coconut milk; COM – cooked with coconut oil and milk; COS – cooked with coconut oil + spices; CMS – cooked with coconut milk + spices; COMS – cooked with coconut oil and milk + spices

dant capacity according to different assays. The highest AAVI values were registered in the extracts cooked with oil and milk (DPPH), milk and spices (ABTS), and with milk (FRAP). The winged bean extracts showed the highest AAVI values when cooked with milk and with oil and milk (DPPH), with oil and milk (ABTS), and with oil (FRAP). Further, the FRAP assay revealed AAVI values of 100% for the winged bean extracts cooked by different methods, except for the sample COMS. This indicates that digestion improved the bioavailability through the release of bioactive compounds by breaking down the food matrix and making the compounds more accessible.

CONCLUSION

Our study revealed that the tested Sri Lankan domestic cooking methods significantly altered the total phenolic content and antioxidant capacity of brinjal, turkey berry, and winged bean extracts. In particular, all the cooking methods increased total phenolic compounds and the antioxidant activity of cooked vegetables compared to their raw forms. According to the ABTS and FRAP assays, all the vegetables exhibited the highest total phenolic content and the highest antioxidant activity when cooked with coconut oil, coconut milk, and spices (COMS). The cooking methods used in the experiments significantly influenced the bioaccessibility of phenolic compounds and antioxidant activity in brinjal, turkey berry, and winged beans. The highest bioaccessibility index for phenolic compounds was found in the brinjal extract cooked with coconut oil (CO) and in the turkey berry and winged bean COMS. Notably, the cooking methods that initially showed higher total phenolics and antioxidant activity did not always correspond to higher bioaccessibility, indicating that digestion might have altered the availability of these compounds.

Our study highlights the variability in the bioavailability of phenolic compounds and antioxidant activity across different cooking methods. According to our results, the choice of a cooking method is crucial for optimizing the bioavailability of health-promoting compounds. There is a need for further investigations on phenolic compounds in bioaccessible and bioavailable extracts cooked by different methods.

CONTRIBUTION

Sameera Priyadarshana was responsible for the conceptualization, methodology, and investigation. Konara Somawathie was involved in the conceptualization, funding acquisition, methodology, resources, supervision, as well as writing the original draft, reviewing, and editing. Mohamed Shafras performed project administration and supervision, as well as wrote, reviewed, and edited the original draft. Darsiga Sivanandarajah carried out formal analysis and wrote, reviewed, and edited the original draft.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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