

## Chromatographic profiling of bioactive polyphenolic compounds and antioxidant evaluation of ethnobotanical leafy vegetables (*Amaranthus spinosus* and *Glinus oppositifolius*) from the hilly regions of Bangladesh

<sup>1,2,\*</sup>Abdullah, A.T.M., <sup>2</sup>Karim, K.M.R., <sup>1</sup>Rahman, M.M., <sup>1</sup>Sharif, M., <sup>1</sup>Khan, T.A. and <sup>2</sup>Islam, S.N.

<sup>1</sup>*Institute of Food Science and Technology, Bangladesh Council of Scientific and Industrial Research, Dhaka, Bangladesh*

<sup>2</sup>*Institute of Nutrition and Food Science, University of Dhaka, Dhaka, Bangladesh*

### Article history:

Received: 23 October 2023

Received in revised form: 14

December 2023

Accepted: 5 September 2024

Available Online: 18

December 2024

### Keywords:

*Amaranthus spinosus*,

*Glinus oppositifolius*,

HPLC-DAD,

Antioxidant property,

Polyphenolic Compounds

### DOI:

[https://doi.org/10.26656/fr.2017.8\(6\).340](https://doi.org/10.26656/fr.2017.8(6).340)

### Abstract

*Amaranthus spinosus* and *Glinus oppositifolius* are leafy vegetables commonly consumed by indigenous populations in the Bandarban hill tracts of Bangladesh due to their distinct sensory characteristics and therapeutic properties. This study aimed to analyze the bioactive polyphenolic compounds in ethanolic extracts of both plants using HPLC-DAD and evaluate their antioxidant potential. Results revealed that *G. oppositifolius* had higher total flavonoid content, total phenolic content, total antioxidant activity and IC<sub>50</sub> values compared to *A. spinosus*. However, *A. spinosus* exhibited a higher total tannin content. The chromatographic analysis identified various bioactive compounds, including gallic acid, epicatechin, quercetin, catechin, rutin hydrate, kaempferol, caffeic acid, and ferulic acid in *A. spinosus*. Similarly, *G. oppositifolius* contained gallic acid, epicatechin, quercetin, catechin, rutin hydrate, caffeic acid, *trans*-ferulic acid, rosmarinic acid, *trans*-cinnamic acid, and vanillin. These polyphenol-rich extracts possess significant antioxidant and anti-inflammatory properties, making them promising candidates for nutraceuticals, functional foods, and industrial applications.

## 1. Introduction

Bandarban, a district in the Chittagong Hill Tracts of Bangladesh, is home to various tribal communities, including the Chakma, Marma, Murang, and Tripura, each with distinct cultural and dietary practices. Ethnic meals in this region feature non-traditional green vegetables, consumed for both nutritional and medicinal purposes (Islam *et al.*, 2010). Two notable leafy vegetables are *Amaranthus spinosus* (accession no. 66570) and *Glinus oppositifolius* (accession no. 66351), locally known as Khadamarech shak and Gima shak, respectively (Bangladesh National Herbarium [BNH], 2023a; BNH, 2023b). These vegetables are valued for their flavor and medicinal benefits (Abdullah *et al.*, 2020).

*Amaranthus spinosus*, a weed widely grown in Bangladesh, is used for its hepatoprotective, anti-diabetic, and anti-inflammatory properties (Sarker and Oba, 2019). It is traditionally used to treat liver diseases, malaria, and stomach issues (Berghofer and Schoenlechner, 2002). *Glinus oppositifolius*, a herbaceous plant, is also consumed as a leafy vegetable

in tribal regions and is known for its therapeutic effects on malaria, joint pain, and skin problems (Diallo *et al.*, 2001; Inngjerdingen *et al.*, 2005).

This study utilized chromatographic analysis to isolate and identify bioactive polyphenols in these vegetables, contributing to the understanding of their chemical composition. The research highlights the nutritional and medicinal value of these ethnic vegetables, advocating for their conservation and the promotion of local, sustainable food sources to enhance dietary diversity and public health.

## 2. Materials and methods

### 2.1 Sample collection

*Amaranthus spinosus* and *G. oppositifolius* were collected from three weekly wholesale markets in Bandarban, Bangladesh (22°11'43.22"N, 92°13'10.06"E). Three samples, each weighing 1.0 kg, were collected for every vegetable from each market. The samples were washed with water, packed in ziplock bags, and transported to the laboratory for further analysis (Islam *et al.*, 2010).

\*Corresponding author.

Email: [tareq\\_dubd@yahoo.com](mailto:tareq_dubd@yahoo.com)

## 2.2 Sample extraction

The edible portions of the plants were freeze-dried at  $-40^{\circ}\text{C}$  using a Thermo Fisher freeze dryer, then ground into powder with a Panasonic grinder. The samples were stored at  $4^{\circ}\text{C}$ , and 20 g of each was extracted with 200 mL of ethanol, agitated for 48 hrs, centrifuged, and filtered. The extracts were stored at  $-20^{\circ}\text{C}$  (Shaheen *et al.*, 2013; Alam *et al.*, 2020; Abdullah, Rahman, Sharif *et al.*, 2024).

## 2.3 Chemicals and reagents

Chemicals and polyphenol standards were obtained from Sigma-Aldrich (St. Louis, USA). Deionized water was produced using a Milli-Q system from Millipore (Bedford, USA).

## 2.4 Yield determination

The extraction yield percentage was calculated to assess the solvent system's effectiveness using the formula:  $\text{yield (\%)} = (A-B) \times 100 / W$ , where A is the extract's weight, B the empty flask's weight, and W the dry sample weight (Abdullah, Rahman, Sharif, Khan and Islam, 2024).

## 2.5 Determination of antioxidant properties

### 2.5.1 Sample preparation

The ASE and GOE were thawed to ambient temperature ( $22^{\circ}\text{C}$ ). Stock solutions ( $10000 \mu\text{g/mL}$ ) were prepared by dissolving 0.1 g extract in 10 mL ethanol and stored at  $4^{\circ}\text{C}$ .

### 2.5.2 Determination of total flavonoid content

The total flavonoid content (TFC) reagent was prepared by dissolving 0.3325 g of aluminum chloride and 1 g of sodium acetate in 100 mL of deionized water. A 0.2 mL stock solution was mixed with 4.8 mL deionized water and 2.5 mL  $\text{AlCl}_3$  reagent, then incubated for 5–6 mins. Absorbance was measured at 430 nm using a UV-VIS spectrophotometer, with quercetin as the standard for total flavonoid content (Abdullah, Sayka, Rahman *et al.*, 2024).

### 2.5.3 Determination of total tannin content

The Folin-Ciocalteu phenol reagent was used to quantify total tannin content. A 0.5 mL stock solution was mixed with 8.5 mL deionized water and 0.5 mL Folin-Ciocalteu reagent, left for 5 mins at room temperature. Then, 1 mL of 35% sodium carbonate solution was added and incubated for 20 mins. Absorbance was measured at 725 nm, and total tannin content (TTC) was expressed as milligrams of tannic acid per gram of dry extract (Haile and Kang, 2019; Abdullah, Rahman, Sharif *et al.*, 2024).

## 2.5.4 Determination of total phenolic content

In a test tube, 8.5 mL of deionized water and 0.5 mL of the stock solution were mixed, followed by the addition of 0.5 mL Folin-Ciocalteu reagent and left for 30 mins at room temperature. Then, 1 mL of 35% sodium carbonate solution was added and incubated for 20 mins. Absorbance was measured at 765 nm and total phenolic content (TPC) was quantified as milligrams of gallic acid per gram of dry extract (Haile *et al.*, 2019; Farzana *et al.*, 2024).

## 2.5.5 Determination of total antioxidant activity

The total antioxidant activity (TAA) of the extract was determined using the phosphomolybdenum method. A 0.5 mL stock solution was mixed with 3.0 mL of reagent containing 0.6 M  $\text{H}_2\text{SO}_4$ , 28 mM  $\text{Na}_3\text{PO}_4$ , and 4 mM ammonium molybdate, then incubated at  $95^{\circ}\text{C}$  for 90 mins. Absorbance was measured at 695 nm, and antioxidant activity was expressed as mg ascorbic acid equivalent per g of extract (Jan *et al.*, 2013; Farzana *et al.*, 2023).

## 2.5.6 Determination of DPPH radical scavenging activity

DPPH radical scavenging activity was measured following the modified methods of Erkan *et al.* (2008) and Rahman *et al.* (2022). A 2 mL 0.2 mM ethanolic DPPH solution was mixed with 2 mL extract solutions at varying concentrations, incubated for 10 mins in the dark, and measured at 517 nm. The percentage of DPPH activity was calculated using  $\{(A_0-A)/A_0\} \times 100$ , and  $\text{IC}_{50}$  was determined by plotting inhibition percentages against extract concentrations (Tanvir *et al.*, 2017).

## 2.6 Identification of bioactive polyphenolic compounds

### 2.6.1 Standard preparation and sample preparation

A  $100 \mu\text{g/mL}$  standard solution of each polyphenol was prepared in methanol, and a mixed standard solution ( $5 \mu\text{g/mL}$  per polyphenol) was made. Calibration curves were plotted by diluting standards to concentrations of 1.0–5.0  $\mu\text{g/mL}$ . ASE and GOE extracts (2.0 mL) were filtered through a  $0.45 \mu\text{m}$  nylon filter and placed in septum vials (Khan *et al.*, 2020; Rahman *et al.*, 2023).

### 2.6.2 Chromatographic system

The chromatographic investigations were performed using a Thermo Fisher Scientific Dionex UltiMate 3000 system, equipped with a quaternary pump (LPG-3400RS), autosampler (WPS-3000), and diode array detector (DAD-3000RS). Phenolic compound separation was achieved using an Acclaim® C18 column ( $4.6 \times 250 \text{ mm}$ ;  $5 \mu\text{m}$ ) at  $30^{\circ}\text{C}$ , with data processed via Dionex Chromeleon software (v6.80). HPLC-DAD followed the

method by Abdullah, Rahman, Sharif, Khan and Islam (2024) using a gradient mobile phase of acetonitrile, acetic acid (pH 3.0), methanol, and 5% IPA. The 20  $\mu$ L injections were monitored at 280 nm, with  $R^2$  values exceeding 0.995.

### 2.7 Statistical analysis

Experimental results were presented as means with standard deviations (SD) and analyzed using IBM SPSS Statistics (v26). Pearson correlation analysis assessed associations, with graphs generated using Past 4.11 and RStudio 2022.12.0.

## 3. Results and discussion

### 3.1 Yield of the extract

The percentage yield of the extract is influenced by the solvent system. The yield percentages observed in both ASE (14.73%) and GOE (13.62%) were found to be similar, as shown in Table 1. The findings of the research were consistent with previous studies regarding the efficacy of solvent extraction in extracting bioactive constituents from plant tissue (Rahman et al., 2022).

### 3.2 Antioxidant properties of extracts

The composition of phytochemical constituents in plant extracts is influenced by the extraction solvent and method (Khoudja et al., 2014). This study evaluated the TFC, TTC, TPC, and TAA in *A. spinosus* extracts and the results showed 1.31 $\pm$ 0.03 mg QE/g, 5.25 $\pm$ 1.31 mg TAE/g, 3.31 $\pm$ 0.02 mg GAE/g, and 3.83 $\pm$ 0.15 mg AAE/g, respectively (Figure 1). The  $IC_{50}$  value for DPPH radical-scavenging activity was 1369.34  $\mu$ g/mL, compared to 15.79  $\mu$ g/mL for ascorbic acid (Table 1). In comparison, Rjeibi et al. (2019) found that total flavonoids, condensed tannins and phenolics content of *A. spinosus* ethanolic extracts was 3.62 mg catechin equivalents (CE)/g DW, 3.15 mg CE/g DW, and 45.2 mg GAE/g DW, respectively which is consistent with this study's findings. House et al. (2020) reported strong antioxidant and anti-inflammatory properties for *A. spinosus*, while Amin et al. (2006) also found significant antioxidant activity in methanolic extracts.

On the other hand, *G. oppositifolius* ethanolic extracts showed higher values for TFC (1.86 $\pm$ 0.03 mg QE/g), TTC (4.57 $\pm$ 0.13 mg TAE/g), TPC (3.39 $\pm$ 0.03 mg GAE/g), TAA (8.21 $\pm$ 0.04 mg AAE/g), and  $IC_{50}$  (713  $\mu$ g/mL) (Table 1 and Figure 1). Kumar et al. (2010) reported 168  $\mu$ g QE/mg for TFC, 40  $\mu$ g pyrocatechol equivalents/mg for TPC, and 6  $\mu$ g  $\alpha$ -tocopherol equivalents/mg for antioxidant capacity, with an  $IC_{50}$  of 1013  $\mu$ g/mL. Studies by Hoque et al. (2011) and Shethi et al. (2018) further confirm the high flavonoid and phenolic content in *G. oppositifolius*, highlighting its strong antioxidant potential. Statistical analysis revealed significant differences between *G. oppositifolius* and *A. spinosus*, with *G. oppositifolius* exhibiting superior polyphenolic activity. TFC, TTC, and TPC showed a strong positive correlation with TAA ( $r = 0.995$ ,  $p < 0.001$ ). Aryal et al. (2019) also observed a significant association between total phenolic, flavonoid content, and antioxidant capacity.

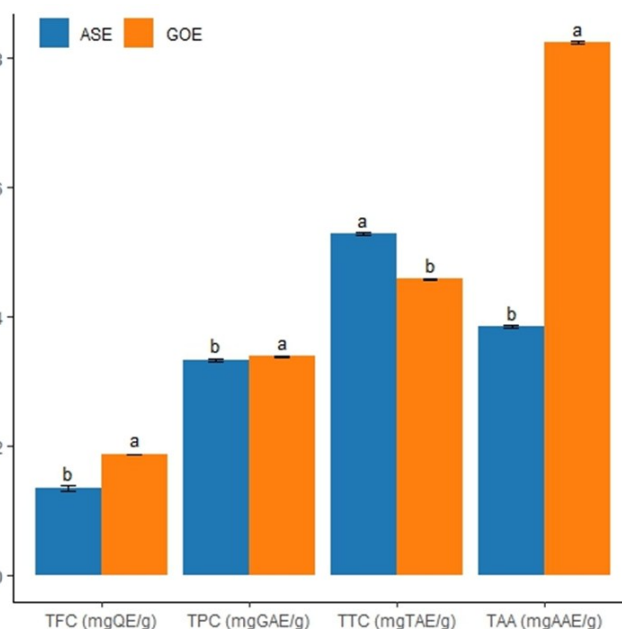


Figure 1. Total flavonoid content (TFC), total tannin content (TTC), total phenolic content (TPC) and total antioxidant activity (TAA) of ethanolic extract of *Amaranthus spinosus* (ASE) and *Glinus oppositifolius* (GOE). Bars with different notations within the same parameter are statistically significantly different at the 5% significance level.

Table 1. Yield and DPPH radical-scavenging activities of *Amaranthus spinosus* and *Glinus oppositifolius* extracts.

Samples	Yield (%)	DPPH scavenging activity ( $IC_{50}$ , $\mu$ g/mL)	Regression equation of % Inhibition ( $R^2$ )
ASE	14.73 $\pm$ 0.84	1369.34 <sup>a</sup>	$y = 8.629\ln(x) - 12.32$ $R^2 = 0.966$
GOE	13.62 $\pm$ 0.76	713.01 <sup>b</sup>	$y = 7.728\ln(x) + 0.769$ $R^2 = 0.989$
Ascorbic Acid	-	15.79 <sup>c</sup>	$y = 14.63\ln(x) + 9.627$ $R^2 = 0.867$

Values are presented as mean $\pm$ SD, n = 3 (three independent extractions). Values with different superscripts are statistically significantly different at the 5% significance level.

### 3.3 Polyphenolic bioactive compounds

In this study, peak purity was assessed using Dionix Chromeleon software (Version 6.80 RS 10), with a purity match criterion set above 98% across a wavelength range of 190 to 650 nm. The permissible criteria for peak purity in polyphenolic analysis utilising HPLC-DAD may exhibit variation depending on the specific polyphenolic molecule under investigation (Marchelak *et al.*, 2020).

Eight polyphenols were identified in the extract of *Amaranthus spinosus* using the same HPLC-DAD conditions applied to 20 standards (Figure 2). As shown in Table 2, caffeic acid was the dominant polyphenolic compound, with gallic acid, catechin hydrate, epicatechin, *trans*-ferulic acid, rutin hydrate, quercetin, and kaempferol also detected. Similarly, Rjeibi *et al.* (2019) found caffeic acid to be the major polyphenolic in ethyl acetate extracts. Stintzing *et al.* (2004) identified various phenolic acids and flavonoids in *A. spinosus* using HPLC-MS, confirming its antioxidant, anti-inflammatory, and anticancer properties (House *et al.*, 2020).

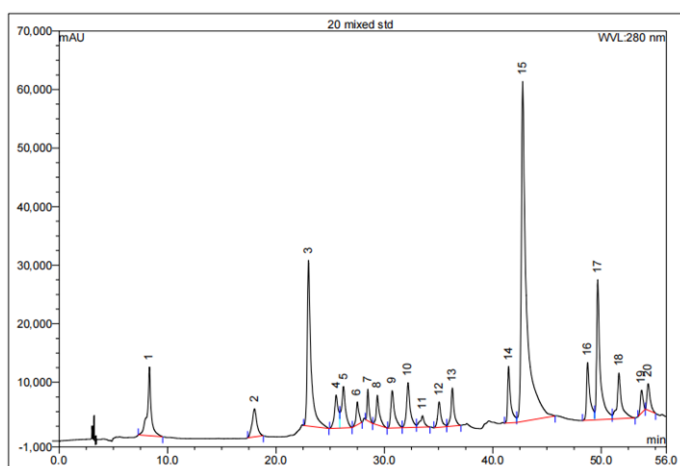


Figure 2. HPLC-DAD chromatogram of 20 bioactive polyphenolic compounds. Where peak: 1 = gallic acid, 2 = catechol, 3 = chlorogenic acid, 4 = catechin hydrate, 5 = vanillic acid, 6 = caffeic acid, 7 = syringic acid, 8 = (-) epicatechin, 9 = vanillin, 10 = *trans*-ferulic acid, 11 = ellagic acid, 12 = *p*-coumaric acid, 13 = rutin hydrate, 14 = rosmarinic acid, 15 = myricetin, 16 = quercetin, 17 = *trans*-cinnamic acid, 18 = naringenin, 19 = kaempferol, 20 = apigenine.

The chromatographic analysis of GOE identified several compounds, including gallic acid, catechin, caffeic acid, epicatechin, vanillin, *trans*-ferrulic acid, rutin hydrate, rosmarinic acid, quercetin, and *trans*-cinnamic acid (Table 2). The primary polyphenols were caffeic acid, *trans*-ferrulic acid, epicatechin, and catechin. *G. lotoides*, from the same genus as *G. oppositifolius*, contains gallic acid, benzoic acid, caffeic acid, chlorogenic acid, and quercetin in its ethanolic

extracts (Awan *et al.*, 2022). Caffeic acid was the predominant compound in both ASE ( $1795.5 \pm 103.94 \mu\text{g/g}$ ) and GOE ( $19560.5 \pm 2887.11 \mu\text{g/g}$ ). Caffeic acid is abundant in medicinal plants and is known for its antioxidant, anticancer, neuroprotective, and anti-inflammatory properties (Alam *et al.*, 2022). GOE had higher concentrations of catechin ( $5182.5 \pm 316 \mu\text{g/g}$ ) and epicatechin ( $6974.5 \pm 236 \mu\text{g/g}$ ) than ASE. Catechins are a group of flavonoids with cardioprotective and antioxidative benefits (Vuong *et al.*, 2010). Epicatechin, in particular, safeguards low-density lipoproteins (LDL) and the vascular endothelium (Schewe *et al.*, 2009). Quercetin was detected in both ASE ( $280.5 \pm 10.6 \mu\text{g/g}$ ) and GOE ( $154 \pm 5.6 \mu\text{g/g}$ ), and it exhibits antinociceptive, antioxidant, analgesic, anti-inflammatory, cardio- and neuroprotective, and antiallergic effects (Ferraz *et al.*, 2021).

Table 2. Composition of the polyphenols in *Amaranthus spinosus* and *Glinus oppositifolius* extracts by HPLC-DAD.

Compound	ASE (mcg/g dry extract)	GOE (mcg/g dry extract)
Gallic acid	119.5±21.92 <sup>a</sup>	271±56.56 <sup>b</sup>
Catechin hydrate	222±2.82 <sup>a</sup>	5182.5±316.07 <sup>b</sup>
Caffeic acid	1795.5±103.94 <sup>a</sup>	19560.5±2887.11 <sup>b</sup>
(-) Epicatechin	488±1.41 <sup>a</sup>	6974.5±236.88 <sup>b</sup>
Vanillin	nd	127.5±10.6
<i>trans</i> -Ferulic acid	257.5±0.70 <sup>a</sup>	7074±81.31 <sup>b</sup>
Rutin hydrate	182.5±24.94 <sup>a</sup>	4005.5±638.51 <sup>b</sup>
Rosmarinic acid	nd	251.5±27.57
Quercetin	280.5±10.6 <sup>a</sup>	154±5.65 <sup>b</sup>
<i>trans</i> -Cinnamic acid	nd	434.5±3.53
Kaempferol	244±72.83	nd

Values are presented as mean±SD, n = 3 (three independent extractions). Values with different superscripts within the same row are statistically significantly different at the 5% significance level. nd: not detected.

A significant amount of rutin hydrate was detected in the GOE sample, with a concentration of  $4005.5 \pm 638.5 \mu\text{g/g}$  dry extract. Rutin hydrate offers multiple health benefits, including anti-inflammatory, antioxidant, and cholesterol-lowering effects, as well as inhibition of platelet aggregation (Imani *et al.*, 2021). Volate *et al.* (2005) also demonstrated rutin's potential in reducing precancerous conditions and inducing apoptosis in colorectal cancers. The GOE extract contained vanillin and rosmarinic acid. Vanillin has bioactive properties such as antibacterial, antimutagenic, anti-inflammatory, and neuroprotective effects (Kim *et al.*, 2019; Costantini *et al.*, 2021). Rosmarinic acid, a phenolic compound derived from caffeic acid, provides antioxidant, anti-inflammatory, and neuroprotective benefits (Alfieri and Mann, 2015). *Trans*-ferulic acid, a potent antioxidant and antibacterial compound, was found in both GOE and

ASE, with the highest concentration (7074±81.31 µg/g) in GOE. It also helps alleviate oxidative stress by modulating gene expression (Guvvala *et al.*, 2019).

Gallic acid was present in ASE (119.5±21.92 µg/g) and GOE (271±56.5 µg/g), offering gastrointestinal and cardiovascular protection, along with hyperglycemia and hypertriglyceridemia reduction (Kahkeshani *et al.*, 2019). Additionally, kaempferol in ASE (244.72±72.83 µg/g) showed anti-cancer and anti-inflammatory potential (Chen and Chen, 2013). *Trans*-cinnamic acid, detected in GOE (434.5±5.53 µg/g), is recognized for its antioxidant, anti-inflammatory, and anticancer properties (Adisakwattana, 2017). In both extracts, catechol, chlorogenic acid, vanillic acid, syringic acid, ellagic acid, *p*-coumaric acid, myricetin, naringenin, and apigenin were not detected. This may be attributed to the choice of extraction solvent, the plant's maturity stage, environmental factors, or limitations of the analytical method.

### 3.4 Pearson's correlation

The Pearson correlation analysis revealed significant relationships among the parameters. Quercetin and kaempferol showed a strong inverse correlation with gallic acid, catechin, caffeic acid, epicatechin, vanillin, ferulic acid, and rutin, while these compounds displayed a positive correlation with cinnamic acid. Quercetin and kaempferol were positively correlated.

## 4. Conclusion

The antioxidant properties of *A. spinosus* and *G. oppositifolius* demonstrate their potential as natural sources of antioxidants. These antioxidants neutralize free radicals and protect cells from oxidative stress, which is linked to various chronic diseases. Chromatographic analysis identified several bioactive polyphenols in these vegetables, known for their health benefits and antioxidant effects. Incorporating *A. spinosus* and *G. oppositifolius* into the diet can enhance nutrient diversity and provide health benefits. These findings may inform dietary guidelines, promote sustainable agriculture, and encourage the cultivation of indigenous crops to improve food security and public health. Future research should focus on their bioavailability, culinary uses, and potential as functional food products.

### Conflict of interest

The authors declare no conflict of interest.

### Acknowledgments

This study was supported by the Bangabandhu Fellowship on Science and ICT, Ministry of Science and

Technology, Bangladesh, with technical assistance from IFST, BCSIR, and INFS, University of Dhaka.

## References

- Abdullah, A.T.M., Rahman, M.M., Sharif, M., Khan, T.A., Islam, S.N. and Karim, K.M.R. (2024). Edible flowers efficiency to boost the thermal oxidation stability of soybean oil: Polyphenolic and antioxidant insights. *Future Foods*, 9, 100338. <https://doi.org/10.1016/j.fufo.2024.100338>.
- Abdullah, A.T.M., Rahman, M.M., Sharif, M., Khan, T.A. and Islam, S.N. (2024). Bioactive polyphenolic compounds and antioxidant potentials of two leafy vegetables in Bangladesh: the *Momordica charantia* and the *Ipomoea aquatica*. *Food Production, Processing and Nutrition*, 6, 35. <https://doi.org/10.1186/s43014-023-00173-w>.
- Abdullah, A.T.M., Sayka, M.I., Rahman, M.M., Sharif, M., Khan, T.A., Jahan, S., Mazumdar, R.M., Uddin, M.N. and Hoque, M.M. (2024). Tea (*Camellia sinensis*) cultivated in three agro-ecological regions of Bangladesh: Unveiling the variability of methylxanthine, bioactive phenolic compound, and antioxidant activity. *Heliyon*, 10(7), e28760. <https://doi.org/10.1016/j.heliyon.2024.e28760>
- Abdullah, M.R., Rahman, M.M., Hemayet, M.A. and Abdul, M. (2020). Diversity of non-conventional vegetables in two ethnic communities of Khagrachari Sadar, Khagrachari, Bangladesh. *International Journal of Forestry, Ecology and Environment*, 2(1), 48-59. <https://doi.org/10.18801/ijfee.020120.06>.
- Adisakwattana, S. (2017). Cinnamic acid and its derivatives: mechanisms for prevention and management of diabetes and its complications. *Nutrients*, 9(2), 163. <https://doi.org/10.3390/nu9020163>.
- Alam, M.K., Rana, Z.H., Kabir, N., Begum, P., Kawsar, M., Khatun, M., Ahsan, M. and Islam, S.N. (2020). Total phenolics, total carotenoids and antioxidant activity of selected unconventional vegetables growing in Bangladesh. *Current Nutrition and Food Science*, 16(7), 1088-1097. <https://doi.org/10.2174/1573401315666191209095515>.
- Alam, M., Ahmed, S., Elasmali, A.M., Adnan, M., Alam, S., Hassan, M.I. and Pasupuleti, V.R. (2022). Therapeutic implications of caffeic acid in cancer and neurological diseases. *Frontiers in Oncology*, 12, e860508. <https://doi.org/10.3389/fonc.2022.860508>
- Alfieri, A. and Mann, G.E. (2015). Bioactive nutraceuticals and stroke: activation of endogenous

- antioxidant pathways and molecular mechanisms underlying neurovascular protection. In *Bioactive Nutraceuticals and Dietary Supplements in Neurological and Brain Disease*, p. 365-379. USA: Academic Press. <https://doi.org/10.1016/B978-0-12-411462-3.00037-0>.
- Amin, I., Norazaidah, Y. and Hainida, K.E. (2006). Antioxidant activity and phenolic content of raw and blanched Amaranthus species. *Food Chemistry*, 94 (1), 47-52. <https://doi.org/10.1016/j.foodchem.2004.10.048>.
- Aryal, S., Baniya, M.K., Danekhu, K., Kunwar, P., Gurung, R. and Koirala, N. (2019). Total phenolic content, flavonoid content and antioxidant potential of wild vegetables from Western Nepal. *Plants*, 8(4), 96. <https://doi.org/10.3390/plants8040096>.
- Awan, A.M., Majeed, W., Javed, F., Aslam, B., Iftikhar, A., Kanwal, H.A. and Fiaz, S. (2022). *Glinus lotoides* ethanolic extract alleviates LPS-induced anxiety and depression-like behavior by modulating antioxidant and inflammatory biomarkers in rats. *Asian Pacific Journal of Tropical Biomedicine*, 12 (2), 78-86. <https://doi.org/10.4103/2221-1691.335696>.
- Bangladesh National Herbarium (BNH). (2023a). Plant Specimen Database Program and Publication. Retrieved on December 12, 2023, from BNH Website: <https://plantsp-eflora.bnh.gov.bd/genus-list?family=Amaranthaceae&genus=Amaranthus&id=362>
- Bangladesh National Herbarium (BNH). (2023b). Plant Specimen Database Program and Publication. Retrieved on December 12, 2023, from BNH Website: <https://plantsp-eflora.bnh.gov.bd/specimen?family=Molluginaceae&genus=Glinus>
- Berghofer, E. and Schoenlechner, R. (2002). Grain Amaranth. In *Pseudocereals and Less Common Cereals*. Berlin, Heidelberg: Springer. [https://doi.org/10.1007/978-3-662-09544-7\\_7](https://doi.org/10.1007/978-3-662-09544-7_7).
- Khoudja, N.K., Boulekbache-Makhlouf, L. and Madani, K. (2014). Antioxidant capacity of crude extracts and their solvent fractions of selected Algerian Lamiaceae. *Industrial Crops and Products*, 52, 177-182. <https://doi.org/10.1016/j.indcrop.2013.10.004>.
- Chen, A.Y. and Chen, Y.C. (2013). A review of the dietary flavonoid, kaempferol on human health and cancer chemoprevention. *Food Chemistry*, 138(4), 2099-2107. <https://doi.org/10.1016/j.foodchem.2012.11.139>.
- Costantini, E., Sinjari, B., Falasca, K., Reale, M., Caputi, S., Jagarlapodii, S. and Murmura, G. (2021). Assessment of the vanillin anti-inflammatory and regenerative potentials in inflamed primary human gingival fibroblast. *Mediators of Inflammation*, 2021, 5562340. <https://doi.org/10.1155/2021/5562340>.
- Diallo, D., Marston, A., Terreaux, C., Toure, Y., Smestad Paulsen, B. and Hostettmann, K. (2001). Screening of Malian medicinal plants for antifungal, larvicidal, molluscicidal, antioxidant and radical scavenging activities. *Phytotherapy research*, 15(5), 401-406. <https://doi.org/10.1002/ptr.738>
- Erkan, N., Ayranci, G. and Ayranci, E. (2008). Antioxidant activities of rosemary (*Rosmarinus Officinalis* L.) extract, blackseed (*Nigella sativa* L.) essential oil, carnosic acid, rosmarinic acid and sesamol. *Food Chemistry*, 110(1), 76-82. <https://doi.org/10.1016/j.foodchem.2008.01.058>.
- Farzana, T., Abedin, M.J., Abdullah, A.T.M. and Reaz, A.H. (2023). Exploring the impact of pumpkin and sweet potato enrichment on the nutritional profile and antioxidant capacity of noodles. *Journal of Agriculture and Food Research*, 14, 100849. <https://doi.org/10.1016/j.jafr.2023.100849>
- Farzana, T., Abedin, M.J., Abdullah, A.T.M., Reaz, A.H., Bhuiyan, M.N.I., Afrin, S. and Satter, M.A. (2024). Enhancing prebiotic, antioxidant, and nutritional qualities of noodles: A collaborative strategy with foxtail millet and green banana flour. *PLoS ONE*, 19(8), e0307909. <https://doi.org/10.1371/journal.pone.0307909>
- Ferraz, C.R., Franciosi, A., Emidio, N.B., Rasquel-Oliveira, F.S., Manchope, M.F., Carvalho, T.T., Artero, N.A., Fattori, V., Vicentini, F.T., Casagrande, R. and Verri Jr, W.A. (2021). Quercetin as an antiinflammatory analgesic. In *A century of valuable plant bioactives*. p. 319-347. USA: Academic Press. <https://doi.org/10.1016/B978-0-12-822923-1.00023-6>.
- Guvvala, P.R., Ravindra, J.P., Selvaraju, S., Arangasamy, A. and Venkata, K.M. (2019). Ellagic and ferulic acids protect arsenic-induced male reproductive toxicity via regulating Nfe2l2, Ppargc1a and StAR expressions in testis. *Toxicology*, 413, 1-12. <https://doi.org/10.1016/j.tox.2018.11.012>.
- Haile, M. and Kang, W.H. (2019). Antioxidant activity, total polyphenol, flavonoid and tannin contents of fermented green coffee beans with selected yeasts. *Fermentation*, 5(1), 29. <https://doi.org/10.3390/fermentation5010029>
- Hoque, N., Imam, M.Z., Akter, S., Mazumder, M.E.H., Hasan, S.R., Ahmed, J. and Rana, M.S. (2011). Antioxidant and antihyperglycemic activities of methanolic extract of *Glinus oppositifolius* leaves. *Journal of Applied Pharmaceutical Science*, 1(7), 50-53.

- House, N.C., Puthenparampil, D., Malayil, D. and Narayanankutty, A. (2020). Variation in the polyphenol composition, antioxidant, and anticancer activity among different *Amaranthus* species. *South African Journal of Botany*, 135, 408-412. <https://doi.org/10.1016/j.sajb.2020.09.026>.
- Imani, A., Maleki, N., Bohlouli, S., Kouhsoltani, M., Sharifi, S. and Maleki Dizaj, S. (2021). Molecular mechanisms of anticancer effect of rutin. *Phytotherapy Research*, 35(5), 2500-2513. <https://doi.org/10.1002/ptr.6977>.
- Inngjerdingen, K.T., Debes, S.C., Inngjerdingen, M., Hokputsa, S., Harding, S.E., Rolstad, B., Michaelsen, T.E., Diallo, D. and Paulsen, B.S. (2005). Bioactive pectic polysaccharides from *Glinus oppositifolius* (L.) Aug. DC., a Malian medicinal plant, isolation and partial characterization. *Journal of Ethnopharmacology*, 101(1-3), 204-214. <https://doi.org/10.1016/j.jep.2005.04.021>.
- Islam, S.N., Khan, M.N.I. and Akhtaruzzaman, M. (2010). A food composition database for Bangladesh with special reference to selected ethnic foods. Institute of Nutrition and Food Sciences. Dhaka, Bangladesh: University of Dhaka.
- Jan, S., Khan, M.R., Rashid, U. and Bokhari, J. (2013). Assessment of antioxidant potential, total phenolics and flavonoids of different solvent fractions of *Monothea buxifolia* fruit. *Osong Public Health and Research Perspectives*, 4(5), 246-254. <https://doi.org/10.1016/j.phrp.2013.09.003>.
- Kahkeshani, N., Farzaei, F., Fotouhi, M., Alavi, S.S., Bahramsoltani, R., Naseri, R., Momtaz, S., Abbasabadi, Z., Rahimi, R., Farzaei, M.H. and Bishayee, A. (2019). Pharmacological effects of gallic acid in health and diseases: A mechanistic review. *Iranian Journal of Basic Medical Sciences*, 22(3), 225-237. <https://doi.org/10.22038/ijbms.2019.32806.7897>
- Khan, T.A., Ipshita, A.H., Mazumdar, R.M., Abdullah, A.T.M., Islam, G.M.R. and Rahman, M.M. (2020). Bioactive polyphenol profiling and in-vitro antioxidant activity of *Tinospora cordifolia* Miers ex Hook F and Thoms: A potential ingredient for functional food development. *Bangladesh Journal of Scientific and Industrial Research*, 55(1), 23-34. <https://doi.org/10.3329/bjsir.v55i1.46729>.
- Kim, M.E., Na, J.Y., Park, Y.D. and Lee, J.S. (2019). Anti-neuroinflammatory effects of vanillin through the regulation of inflammatory factors and NF- $\kappa$ B signaling in LPS-stimulated microglia. *Applied Biochemistry and Biotechnology*, 187, 884-893. <https://doi.org/10.1007/s12010-018-2857-5>.
- Kumar, B.S.A., Lakshman, K., Jayaveera, K.N., Shekar, D.S., Nandeesh, R. and Velmurugan, C. (2010). Chemoprotective and antioxidant activities of methanolic extract of *Amaranthus spinosus* leaves on paracetamol induced liver damage in rats. *Acta Medica Saliniana*, 39(2), 68-74. <https://doi.org/10.5457/ams.159.10>.
- Marchelak, A., Olszewska, M.A. and Owczarek, A. (2020). Simultaneous quantification of thirty polyphenols in blackthorn flowers and dry extracts prepared thereof: HPLC-PDA method development and validation for quality control. *Journal of Pharmaceutical and Biomedical Analysis*, 184, 113121. <https://doi.org/10.1016/j.jpba.2020.113121>
- Rahman, M.M., Abdullah, A.T.M., Sharif, M., Jahan, S., Kabir, M.A., Motalab, M. and Khan, T.A. (2022). Relative evaluation of in-vitro antioxidant potential and phenolic constituents by HPLC-DAD of Brassica vegetables extracted in different solvents. *Heliyon*, 8(10). e10838. <https://doi.org/10.1016/j.heliyon.2022.e10838>
- Rahman, M.M., Dipti, T.T., Islam, M.N., Abdullah, A.T.M., Jahan, S., Alam, M.M. and Karim, M.R. (2023). Chemical composition, antioxidant and antibacterial activity of *Piper chaba* stem extracts with preservative effects on storage of raw beef patties. *Saudi Journal of Biological Sciences*, 30(6), 103663. <https://doi.org/10.1016/j.sjbs.2023.103663>
- Rjeibi, I., Ben Saad, A., Sdayria, J., Feriani, A., Ncib, S., Allagui, M.S., Hfaiedh, N. and Souid, S. (2019). HPLC-DAD identification of polyphenols from ethyl acetate extract of *Amaranthus spinosus* leaves and determination of their antioxidant and antinociceptive effects. *Inflammopharmacology*, 27 (5), 975-984. <https://doi.org/10.1007/s10787-018-0482-0>
- Sarker, U. and Oba, S. (2019). Nutraceuticals, antioxidant pigments, and phytochemicals in the leaves of *Amaranthus spinosus* and *Amaranthus viridis* weedy species. *Scientific Reports*, 9(1), 20413. <https://doi.org/10.1038/s41598-019-50977-5>.
- Schewe, T. and Sies, H. (2009). Epicatechin and its role in protection of LDL and of vascular endothelium. In *Beer in Health and Disease Prevention*, p. 803-813. USA: Academic Press. <https://doi.org/10.1016/b978-0-12-373891-2.00082-1>.
- Shaheen, N., Rahim, A.T.M., Mohiduzzaman, M., Banu, C.P., Bari, L.M., Basak Tukun, A., Mannan, M.A., Bhattacharjee, L. and Stadlmayr, B. (2013). Food composition table for Bangladesh. Dhaka, Bangladesh: Institute of Nutrition and Food Science Centre for Advanced Research in Sciences, University of Dhaka.

- RESEARCH PAPER
- Shethi, K.J. and Uddin, M.Z. (2018). Antioxidant potential of five commercially less valued leafy vegetables from Bangladesh. *Bangladesh Journal of Botany*, 47(4), 953-959. <https://doi.org/10.3329/bjb.v47i4.47391>.
- Stintzing, F.C., Kammerer, D., Schieber, A., Adama, H., Nacoulma, O.G. and Carle, R. (2004). Betacyanins and phenolic compounds from *Amaranthus spinosus* L. and *Boerhavia erecta* L. *Zeitschrift für Naturforschung C*, 59(1-2), 1-8. <https://doi.org/10.1515/znc-2004-1-201>
- Tanvir, E.M., Hossen, M.S., Hossain, M.F., Afroz, R., Gan, S.H., Khalil, M.I. and Karim, N. (2017). Antioxidant properties of popular turmeric (*Curcuma longa*) varieties from Bangladesh. *Journal of Food Quality*, 2017(1), 8471785. <https://doi.org/10.1155/2017/8471785>
- Volate, S.R., Davenport, D.M., Muga, S.J. and Wargovich, M.J. (2005). Modulation of aberrant crypt foci and apoptosis by dietary herbal supplements (quercetin, curcumin, silymarin, ginseng and rutin). *Carcinogenesis*, 26(8), 1450-1456. <https://doi.org/10.1093/carcin/bgi089>.
- Vuong, Q.V., Golding, J.B., Nguyen, M. and Roach, P.D. (2010). Extraction and isolation of catechins from tea. *Journal of Separation Science*, 33(21), 3415-3428. <https://doi.org/10.1002/jssc.201000438>.