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Comparative evaluation of bioactive component and antioxidant activities of *Cinnamomum zeylanicum* grown in Bangladesh

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Abstract

This study aims to evaluate the bioactive components, phytochemicals, and antioxidants of different cinnamon cultivars. The SCZ-006 cultivar was found to contain a significantly higher amount of the most valuable bioactive compound cinnamaldehyde (78.54 %) compared to the local Daruchini (64.82 %) variety, commonly used for its strong aromatic flavor in food processing, cosmetics, confectionaries, and pharmaceuticals. The proximate nutrient composition of SCZ-006 showed higher contents of fiber (29.38 %), lipid (5.42 %), protein (5.97 %), and carbohydrate (58.73 %) than the local Daruchini variety. Additionally, the SCZ-006 cultivar barks were enriched with minerals such as calcium, iron, zinc, potassium, phosphorus, and magnesium. Total phenolic and flavonoid contents were also significantly higher in cultivar SCZ-006 (186.41 mg GAE/100 g and 69.97 mg QE/100 g, respectively) compared to the local Daruchini (154.57 mg GAE/100 g and 66.16 mg QE/100 g) variety. The antioxidant capacity was determined by DPPH (2, 2-diphenyl-1-picrylhydrazyl) and FRAP (ferric reducing antioxidant power) assays and was showed significantly higher inhibitory capacity in SCZ-006 (53.26 % and 34.01 mg GAE/100 g) than in the local Daruchini variety (67.76 % and 41.95 mg GAE/100 g). Therefore, the SCZ-006 cultivar is identified as the most promising and nutritionally rich variety.

Keywords: Antioxidant capacity, cinnamaldehyde, essential cinnamon oil, flavonoid, proximate composition

Introduction

Cinnamomum zeylanicum or true cinnamon is recognized as a valuable traditional spice of the Lauraceae family due to its historical and global significance. Its exceptional nutritional composition and health benefits have led to its widespread cultivation and consumption. In Bangladesh, it is commonly known as 'Daruchini' and is extensively used as a spice. This tropical evergreen tree's bark powder is renowned for its aromatic flavor and sweet taste, finding applications in cooking and traditional and modern medicinal perspectives (Husain *et al.*, 2018, Ashfaq *et al*., 2021) [1, 2]. The cinnamon bark powder is mixed for preparing many kinds of deserts, sauces, spicy candies, pickles, teas, fast food seasonings, confectionery products, dental, cola-type drinks, and traditional foods because of its aromatic flavor (Paliwal *et al.,* 2018) [3]. Cinnamon oil, extracted from the bark of cinnamon, is used in numerous pharmaceutical preparations to treat ailments such as the flu, headache, joint pain, gastric issues, intestinal disorders, respiratory problems, and cardiac diseases (Saleem *et al.,* 2015) [4].

Cinnamon contains various bioactive components such as *trans*-cinnamaldehyde, eugenol, linalool, cinnamic acid, cinnamate, volatile terpenoids, essential oils, hydroxycinnamic acids, phenolic acids, flavonoids and antioxidants, which display diverse biological activities (Jaganath and Crozier, 2009)[5]. Indeed, *trans*-cinnamaldehyde, eugenol, and linalool together constitute more than 82.5 % of *C. zeylanicum's* composition (Albuquerque *et al.*, 2021) [6]. These components provide anti-inflammatory, antidiabetic, analgesia, gastroprotective, bronchodilator, and anticancer benefits (Sharifi-Rad *et al.,* 2021, Das *et al.,* 2022) [7, 8]. Additionally, cinnamaldehyde is extensively used for flavorings, food processing, cosmetics, and bakery goods (Abdelwahab *et al.,* 2017) [9]. Besides, cinnamon essential oil and phytochemicals (phenolics, flavonoids, alkaloids, and polyphenolic compounds) are rich sources of antioxidants, which protect cell membranes from free radical damage (Alfadda and Sallam, 2012, Ismail *et al.,* 2017, Zhao *et al.,* 2021) [10, 11, 12]. Moreover, the presence of these compounds in plants has garnered increased attention due to their ability to scavenge reactive oxygen species. As a result, they are highly valued for their potential incorporation into daily diets to enhance overall health (Assefa *et al.,* 2018, Gupta *et al.,* 2013) [13, 14]. They are considered effective remedies for various diseases, including type-II diabetes, as they improve insulin and normal blood sugar levels as well as, arteriosclerosis, arthritis, and Alzheimer's (Hussein, 2022, Stevens and Allred, 2022) [15, 16]. Cinnamon is also used to cure cough, sore throats, diarrhea, respiratory, and stomach disorders (flatulence, nausea, and abdominal cramps) anti-septic, anti-allergic, cardiac diseases, and neurological benefits (Ismail *et al.,* 2017) [11]. Recently, during the COVID-19 pandemic situation, the use of cinnamon bark was enhanced in Bangladesh as a means to bolster immunity. Although the antioxidant activity and phenolic compound contents of spices have been widely investigated, a comprehensive study on their qualitative and quantitative characteristic in various extractions of the antioxidant activity measurements is still lacking. Moreover, the information on the antioxidant activity and bioactive components of cinnamon is rather limited, as the spice is mainly studied as a source of fatty acids. However, the antioxidant activity, bioactive

compounds, and phytochemicals of its extractive bark oil remain under-explored. Therefore, this study aims to compare the chemical components such as bioactive (cinnamaldehyde for aroma), phytochemicals, and antioxidant activity of the local cinnamon variety and promising cultivars in Bangladesh and to provide comprehensive information on the nutritional and health benefits of these cultivars.

Materials and Methods

Sample collection and preparation

Twenty-five cinnamon cultivar samples were collected from the Spices Research Centre (SRC), Bangladesh Agricultural Research Institute (BARI), and Bangladesh and were implemented at the Central Laboratory, Research Wing, and BARI. Prior to this study, the cultivars were subjected to evaluation for yield and yield-related characteristics (BARI, 2020). Among them, the popular variety BARI Daruchini-1, and SCZ-006 cultivars were collected from SRC, BARI, while a local Daruchini (control) sample was purchased from a commercial retail shop in Gazipur city, Bangladesh. The selected cultivars SCZ-006, BARI Daruchini-1, and local Daruchini were included in the study. The samples were cleaned and dried in an oven at 40-45 ºC for 12 h. The dried barks were then ground to powder by using a grinder with a 0.5 mm sieve. The resulting powder was stored in sealed airtight containers prior to extraction.

Proximate analysis of cinnamon barks

The proximate composition analysis of cinnamon barks was determined, according to the Association of Official Analytical Chemists (AOAC. 2000) [17] methods. The crude protein content was analyzed using the micro Kjeldahl method (AOAC, 928.08). The Kjeldahl method was applied to evaluate the nitrogen content in the different samples. Total protein was calculated by multiplying the amount of nitrogen with a conversion factor of 6.25. Crude fat was extracted from sample using Soxhlet extractor apparatus with petroleum ether according to the method (AOAC, 920.39c). The automated fiber analyzer (Auto-Fibre Analyzer, Foss, USA) was used to measure the fiber content of cinnamon samples, using the method of the AOAC, 921.13. The fat and moisture free cinnamon bark powder samples were carried out by treating with 1.25% dilute acid (H_2SO_4) and 1.25% alkali (NaOH) for 30 min followed by washing with distil water and ignition of the residue. The samples were cool in a desiccator and then weighed. The cool samples were incinerated in Muffle furnace at 550°C for 30 min and then weighed. Ash content was measured by muffle furnace ashing at 500°C for 5–6 h (AOAC, 923.03). Moisture content was determined by oven drying method at 100–105°C for 6-12 h (AOAC, 950.46). The total carbohydrate content was measured according to the anthrone colorimetric method explained by James *et al.* (AOAC. 2000). Briefly, 100 mg bark powder samples were carried out by treating with 2.5 N HCl boling water bath (80-90°C) for 3 h followed by neutralized with sodium carbonate (Na_2CO_3), and the supernatant (100 µl) was mixed with 4 ml anthrone solution. After that, the mixture was boiling water bath for 10 min. The absorbance at 620 nm was measured using a UV-Vis spectrophotometer (Shimadzu UV-3600i, Japan)

Energy value

The energy value of cinnamon bark was calculated using the following formula:

Total energy values (kcal/100 g) = (% Carbohydrate × 4) + (% Crude fat × 9) + (% Crude protein × 4)

Extraction of bark essential oil and measurement of bioactive components

The dried cinnamon barks were cut into small pieces and were ground using a grinder with a 0.5 mm sieve for particle size. The powdered bark samples (250 g) were placed in a round bottom flask which was connected to the condenser. After that, 700 ml methanol was added, and the flask was placed in a heating mantle. Initially, the samples were heated at 60ºC and increased gradually up to 100ºC and stored at 4ºC following a modified method described by Hossain *et al.,* (2023) [18]. The oil samples (100 µl) were treated with 5 ml of ethylated reagent (sodium hydroxide, ethanol, and petroleum ether mixed), then vortexed in plastic tubes and put in overnight at normal temperature. Then, the sample was mixed with 5 ml salt solution (sodium hydrogen sulphate and sodium chloride mixed) shaking well and incubated for 10 min at room temperature. The upper oily layer was collected in a vial and injected into a gas chromatography with mass spectrometry (GC-MS) (Shimadzu, GC-MS 2010, Japan). The chemical composition analysis in samples was conducted using GC-MS with the following settings such as a silica capillary column (30 m x 0.25 µm), flame-ionization detector, carrier gas helium, make-up gas hydrogen and nitrogen, split ratio 50:1, autosampler, and injection volume (2 µl). Individual peaks were identified using retention times for the individual components by comparing their standards and running on the same column under the same conditions. The percentage of fatty acids was calculated as the ratio of the partial area to the total peak area of fatty acid methyl ester (FAMEs).

Mineral content of cinnamon bark

The mineral content of cinnamon barks was measured using a modified method described by Petersen (2002) [19]. Briefly, cinnamon bark powder (1 g) was treated with concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) (5:1, v/v), and left at room temperature overnight. The mixture was then digested at 120ºC to 240ºC. Digested samples were cooled in an ice bath, diluted to 30 ml with deionized water, and filtered through Whatman filter paper. The filtrate was analyzed for sodium, calcium, iron, potassium, zinc, magnesium, manganese, and copper via atomic absorption spectrometry (AAS, Shimadzu AA-6800, Japan) and for phosphorus using UV-spectrophotometer (Shimadzu UV-3600). Individual minerals were quantified by comparing the corresponding standard mineral procured from Sigma Aldrich Chemical Co., USA.

Analysis of phytochemicals and antioxidant activity

Sample preparation and extraction

The dried cinnamon barks were cut into small pieces and were ground to powder by using a grinder, and 60-micron sieve was used to pass the powder. Five grams of cinnamon bark powder were extracted with 50 ml of methanol (1:10, w/v) in a shaker (GFL 3015, Germany) at room temperature for 12 h. After that, the mixture was centrifuged at 11500 rpm for 15 min. The extract was collected into a tube. Finally, the extract or stock solution was stored at -20ºC for further analysis according to the below procedure.

Total phenolic content of cinnamon bark

Total phenolic content (TPC) was measured using the Folin-Ciocalteau method explained by John *et al.,* 2014 [20]. Briefly, 50 µl of the extract was mixed with 1 ml of Folin-Ciocalteu reagent (diluted 1:10 with distiled water) and 950 µl of methanol, then thoroughly shaken and incubated for 5 minutes. Following this, 1 ml of 7.5 % (w/v) sodium carbonate (Na_2CO_3) was added, and the mixture was incubated for 30 minutes in a dark place at room temperature. Subsequently, the absorbance at 765 nm was measured using a UV-Vis spectrophotometer (Shimadzu UV-3600i, Japan) and TPC was calculated using a gallic acid standard curve and expressed as mg gallic acid equivalent per gram sample. All tests were performed in triplicates.

Total flavonoid content of cinnamon bark

Total flavonoid content **(**TFC) was determined using the aluminum chloride colorimetric assay method described by John *et al.,* 2014[20]. Briefly, extract (500 µl) was mixed with 0.25 ml of 5 % sodium nitrate and 1.5 ml of methanol, and then thoroughly shaken. After adding 0.25 ml of 10 % aluminum chloride ($AlCl_3$), the mixture was incubated in the dark for 20 minutes. Then, 1 ml of 4 % NaOH was added and incubated for another 20 minutes. The volume was adjusted to 5 ml with methanol. After incubation, absorbance at 510 nm was measured by a spectrophotometer. TFC was calculated using a quercetin standard curve and expressed as mg quercetin equivalents (QE) per g sample. All tests were performed in triplicates.

Determination of antioxidant capacity

DPPH (2, 2-diphenyl-1-picrylhydrazyl) free radical scavenging capacity

DPPH free radical scavenging capacity was measured using a modified method by Brand-Williams *et al.,* 1995. Briefly, 500 µl of the extract was mixed with 2 ml of 0.1 mM DPPH (w/v in ethanol) solution and 0.4 ml of methanol. The mixture was shaken and incubated in the dark for 30 min at room temperature. Absorbance was measured at 517 nm using a UV–Vis spectrophotometer. Gallic acid was used as a positive control. The analysis was done in triplicates. The inhibition percentage was calculated using the following formula:

Inhibition % = $[(A_c - A_s)/A_c]*100$

Where, A_c shows the absorbance of the control and A_s shows the absorbance of the sample

Determination of ferric-reducing antioxidant power (FRAP)

The ferric-reducing antioxidant power assay was determined using the method described by Benzie and Strain, 1996 [21]. This method monitors the reduction of a ferric tripyridyltriazine complex (Fe^{+3}-TPTZ) to a ferrous complex (Fe^{+2}-TPTZ) by the extract was observed at 596 nm. Briefly, 200 µl of the extract was mixed with 1.8 ml methanol and 500 µl freshly prepared FRAP reagent [(300 mM acetate buffer, pH 3.6, 10 mM TPTZ (2, 4, 6-tripyridyl-s-triazine) in 40 ml of 40 mM HCl, and 20 mM $FeCl_3$ at 10:1:1 (v/v/v)], incubated at 37ºC. After that, the mixture was shaken and incubated for 15 min in a dark drawer at room temperature. The resulting ferrous complex was quantified spectrophotometrically at 596 nm. The FRAP results were expressed as mg of gallic acid equivalent (GAE) per g of sample. The analysis was performed in triplicates.

Statistical analysis

Data were analyzed using SPSS 17.0 software. Each experimental condition was replicated three times with triplicate analyses. Results are presented as mean ± standard deviation (SD). One-way ANOVA followed by Tukey's multiple comparison tests was used to determine significant differences among groups.

Results and Discussion

The bioactive components of cinnamon bark oil

The volatile essential oil of cinnamon bark has outstanding antioxidant properties due to its bioactive constituents. This study evaluated the chemical components of bark oil by using a gas chromatography-mass spectrophotometer (GC-MS). The analysis of bark oil from BARI Daruchini-1, cultivar SCZ-006, and local Daruchini variety identified 16 chemicals or bioactive elements, as shown in Table 1, Fig 1, Fig 2, and Fig 3. The most abundant components were *trans*-cinnamaldehyde (64.82 to 78.54 %), eugenol (4.94 to 8.55 %), limonene (1.47 to 3.23 %), *p*-cymene (1.09 to 3.13 %), *β*- caryophyllene (1.75 to 2.73 %), linalool (1.30 to 2.41 %) and *α*-humulene (1.67 to 2.09 %). Other significant elements included *α*-pinene (0.73 to 1.82 %), eucalyptol (0.79 to 2.20 %), cinnamyl ester (0.37 to 1.23 %), terpinene (0.18 to 0.94 %), cadinene (0.13 to 1.39 %), isoborneol (0.39 to 1.63 %), benzyl benzoate (0.32 to 1.38 %), and benzaldehyde (0.14-0.52 %). The strong spicy pleasing aromatic flavor of cinnamon is primarily due to cinnamaldehyde. Our results align with the findings of Marongiu *et al.,* (2007) [22] and Shan *et al.,* (2007) [23] which reported high levels of *trans*-cinnamaldehyde in cinnamon bark oil, ranging from 77 to 79 %. Traditionally, it is used for its aroma, medicinal purposes, and essence compounds (Rao and Gan, 2014) [24]. Additionally, its active constituents and phenolic or phenylpropanoid compounds enhance defense against reactive oxygen species (ROS) induced by hyperglycemia and protect cells by reducing lipid peroxidation (Zhao *et al.,* 2021). Eugenol (4-allyl-2-methoxy phenol) is another important element that prevents ROS formation under conditions related to diabetes, inflammation diseases, and cancer by breaking peroxidation cascade and scavenging radicals (Aminzare *et al.,* 2018, Tungmunnithum *et al.,* 2018) [25, 26]. The results revealed that the cultivar SCZ-006 had a significantly higher content of *trans*-cinnamaldehyde and eugenol than the BARI Daruchini-1 and the local Daruchini variety. These findings align with previous research, which consistently identifies cinnamaldehyde as the primary constituent of cinnamon bark oil (Al-Reza *et al.,* 2010, Behbahani *et al.,* 2020) [27, 28].

Table 1: Results of the chemical and bioactive components in cinnamon bark oil

Variety/ cultivars	Content (%)															
	α- pinene	Benzaldehyde	Eugenol	Eucalyptol	*p*-Cymene	Linalool	*(E)*-cinaamaldehyde	Terpinene	Cinnamyl ester	*β*-Caryophyllene	Cadinene	Calamene	*α*-Humulene	Limonene	Isoborneol	Benzyl benzoate
BARI Daruchini-1	0.73 ± 0.05c	0.14 ± 0.03c	8.55 ± 0.46a	1.52 ± 0.11b	1.21 ± 0.11b	2.41 ± 0.09a	71.39 ± 0.73b	0.18 ± 0.02c	1.19 ± 0.05a	2.73 ± 0.08 a	0.13 ± 0.02c	1.07 ± 0.11b	2.09 ± 0.05a	3.23 ± 0.09a	1.63 ± 0.09a	0.47 ± 0.04b
SCZ-006	1.15 ± 0.03b	0.35 ± 0.03b	6.50 ± 0.54b	2.20 ± 0.03a	1.09 ± 0.04b	1.64 ± 0.06b	78.54 ± 0.63a	0.44 ± 0.02b	0.37 ± 0.02b	1.92 ± 0.04b	0.83 ± 0.03b	0.73 ± 0.03c	1.67 ± 0.03b	1.94 ± 0.04b	0.49 ± 0.03b	0.32 ± 0.03c
Local Daruchini	1.82 ± 0.03a	0.52 ± 0.03a	4.94 ± 0.04c	0.79 ± 0.04c	3.13 ± 0.04a	1.30 ± 0.04c	64.82 ± 0.11c	0.94 ± 0.04a	1.23 ± 0.02a	1.75 ± 0.04c	1.39 ± 0.03a	2.07 ± 0.04a	1.74 ± 0.02b	1.47 ± 0.03c	0.39 ± 0.03b	1.08 ± 0.03a
CV	3.22	1.17	4.18	4.27	3.65	3.86	1.12	5.04	3.33	2.50	3.09	5.22	1.80	2.82	2.93	4.85

Values are presented as mean ± SD (n = 3). Means with different superscripts within a row differ significantly ($p \leq 0.05$) by ANOVA and Tukey's test

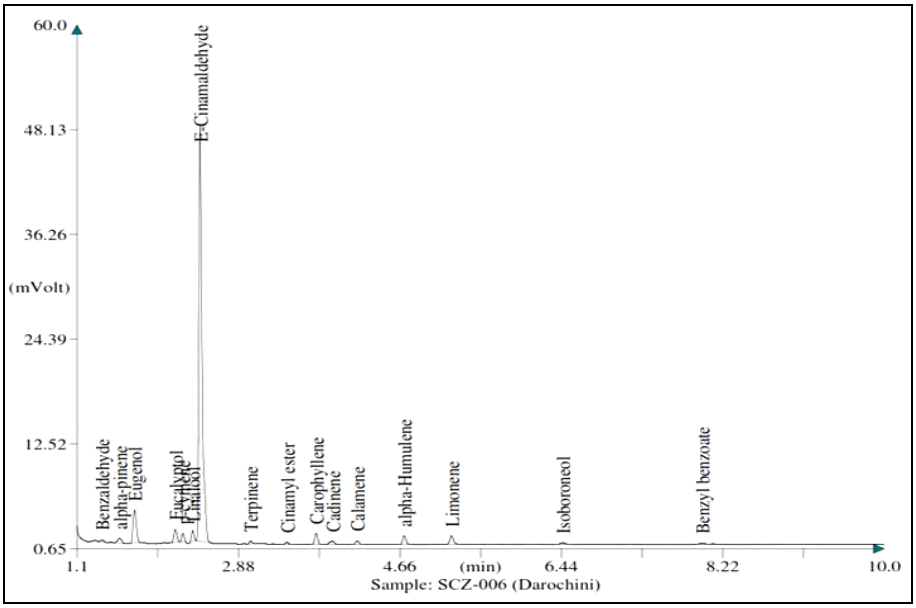

Fig 1: Chromatogram of the chemical and bioactive components of cultivar SCZ-006 bark Oil

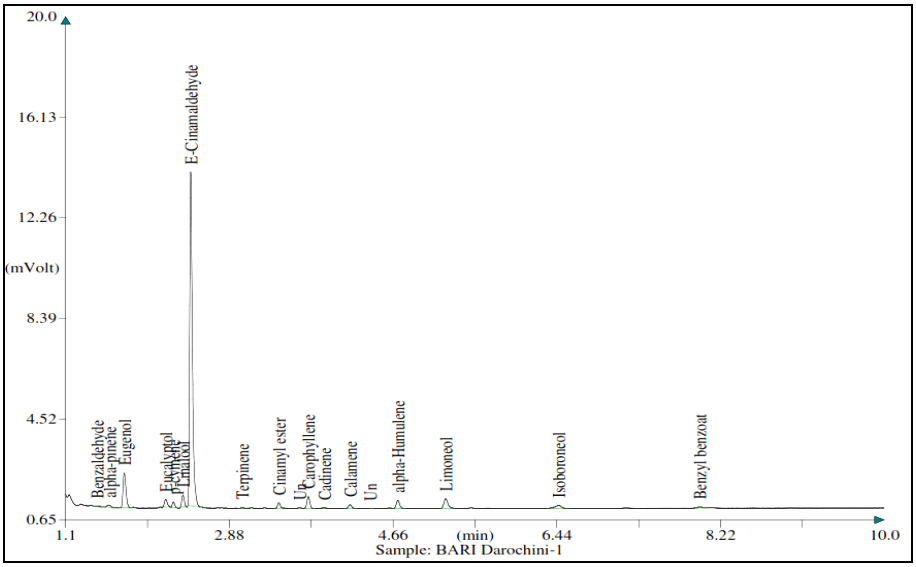

Fig 2: Chromatogram of the chemical and bioactive components of BARI Daruchini-1 bark oil

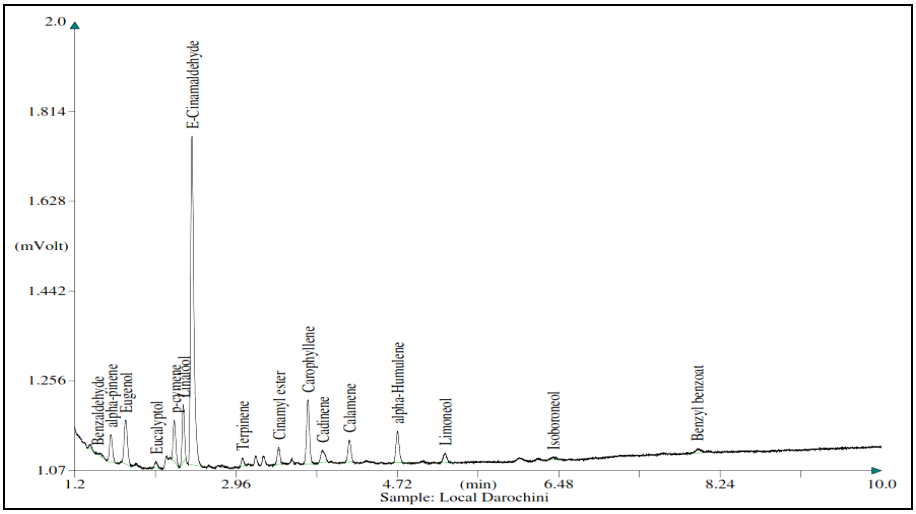

Fig 3: Chromatogram of the chemical and bioactive components of Local Daruchini bark oil

Nutrient composition of cinnamon cultivars

The proximate nutrient composition of cinnamon barks is shown in Table 2. The crude fiber, crude fat, crude protein, moisture, ash, total carbohydrate, and energy values ranged from 25.86 to 29.38 %, 3.83 to 5.42 %, 4.45 to 6.22 %, 48.80 to 55.52 %, 4.84 to 5.87 %, 3.01 to 3.82 %, and 265.75 to 294.32 kcal/100 g in cultivar SCZ-006, BARI Daruchini-1, and local Daruchini variety, respectively. Our results showed that the cultivar SCZ-006 had significantly highest content of proximate nutrients compared to the local variety. The fibre, fat, protein, and carbohydrates were the primary components of Bangladeshi cinnamon, aligning closely with fiber and carbohydrate values reported by Lartey *et al.,* (2023) [29] and Sana *et al.,* (2019) [30]. The spongy mass of fiber helps to satisfy the appetite of consumers and it also assists the movement of food through the alimentary canal by aiding the muscular action of the intestine thereby reducing the risk or incidence of constipation (Edem *et al.,* 2009) [31]. Carbohydrate content varied between the cultivars, with values of 48.80 to 55.52 % (Table 2). Carbohydrates provide energy for cellular and tissue function, with the higher carbohydrate content in SCZ-006 cultivar suggesting greater energy potential upon consumption of the body. Besides, carbohydrates in spices are very essential spices play a crucial role in mitigating the detrimental effects of cholesterol and saturated fat, particularly for individuals with diabetes (Xue *et al.,* 2017) [32]. Notably, cultivar SCZ-006 exhibited a higher fat content compared to findings reported by Gul and Safdar (2009) [33] and Shumaila *et al.,* (2009) [34]. Additionally, cinnamon fat is crucial for ensuring the absorption of aroma or flavor, thereby increasing the palatability of food (Lartey *et al.,* 2023) [29]. Protein is another essential nutrient involved in various bodily functions, including cell repairs, tissue building, blood formation, and immune system support (Kaur *et al.,* 2019) [35]. The protein content of cultivar SCZ-006 was also higher than the local variety. Our results compared with the results which were observed by Sana *et al.,* (2019) [30] and Wu *et al.,* (2022) [36]. The ash content was found to be consistent with other studies, ranging from 3.01 to 3.82 % (Gul and Safdar, 2009) [33]. These mineral components within the ash content could potentially offer significant health benefits. Cinnamon bark is used for domestic purposes and moisture level plays an important role during storage conditions. In the present study, the moisture content of cinnamon bark ranged from 4.84 to 5.87 % which was similar reported by Sana *et al.,* (2019) [30]. Above 10 % moisture level can expose cinnamon products to early spoilage (Ajuru *et al.,* 2017) [37]. Overall, cinnamon bark is a valuable source of essential nutrients that are essential for human health. Therefore, proximate nutrient parameters of cinnamon may vary depending on different cultivars, regions, maturity stage, harvesting time, length of drying time, storage conditions, origin, environmental conditions, and geographic conditions.

Table 2: Results of proximal analysis in bark of cinnamon cultivars

Variety/cultivars	Content (%)						Energy (Kcal/100g)
	Crude Fibre	Crude Fat	Crude Protein	Carbohydrate	Moisture	Ash	
BARI Daruchini-1	25.86 ± 0.53b	4.07 ± 0.11b	6.22 ± 0.20a	52.12 ±0.57b	5.28 ± 0.54a	3.73 ± 0.25a	293.82±4.59a
SCZ-006	29.38 ± 0.18a	5.42 ± 0.09a	5.97 ± 0.11a	48.80 ± 0.94c	4.84 ± 0.55a	3.01 ± 0.67b	294.32±4.33a
Local Daruchini	26.16 ± 0.676b	3.83 ± 0.13b	4.45 ± 0.28b	55.52 ± 0.91a	5.87 ± 0.55a	3.82 ± 0.19a	265.75±3.83b
CV	1.87	2.48	3.76	1.58	1.30	1.35	1.49

Values are presented as mean ± SD (n = 3). Means with different superscripts within a row differ significantly ($p \leq 0.05$) by ANOVA and Tukey's test

Mineral composition in cinnamon cultivars

Minerals are essential inorganic substances needed at a certain amount for the proper functioning of human cells. The mineral composition of three cinnamon cultivars is presented in Table 3 for a comparison of the results obtained with cinnamon-selected cultivars and variety values are also included. The analysis of 100 g cinnamon bark powder contains calcium (632.33 to 713.33 mg), potassium (765.67 to 874.67 mg), magnesium (513.66 to 578.67 mg), phosphorus (278.00 to 414.67 mg), sodium (3.99 to 5.25 mg), iron (7.82 to 9.32 mg), zinc (3.07 to 4.05 mg), manganese (14.85 to 19.22 mg), and copper (0.46 to 0.75 mg) from BARI Daruchini-1, cultivar SCZ-006, and local Daruchini variety. Potassium (K) and calcium (Ca) are the most abundant minerals, whereas iron (Fe) and zinc (Zn) are the least. These results align with the findings by Shumaila *et al.,* (2009) [34] and Sana *et al.,* (2019) [30], highlighting K and Ca as major components. Potassium is crucial for maintaining water, electrolyte, and acid-base balance and proper nerve and muscle function (Shumaila and Mahpara, 2009).

Phosphorus (P) is the second most abundant mineral in cinnamon, following calcium, as reported by Goel and Mishra (2020) [38]. This significant phosphorus content makes cinnamon a valuable dietary addition for supporting heart health, cell growth, bone formation, and blood sugar regulation (Indrayan *et al.,* 2005) [39]. Calcium, another key mineral, plays a critical role in various bodily functions, including tissue health, enzyme activity, and physiological processes. Magnesium, iron, and sodium, also present in cinnamon, are essential for energy metabolism, enzyme function, and overall health prevention. Zinc found in varying concentrations in plant foods and is essential for enzyme structure and activity. The nutritional composition and mineral content of plant can vary significantly based on factors such as soil type, plant genetics, geographical location, plant maturity, and environmental conditions (Vilkickyte and Raudone, 2021, Woziwoda *et al.,* 2021) [40, 41].

Table 3: Mineral content of different cinnamon cultivars

Variety/cultivars	Amount in mg/100g								
	Calcium	Potassium	Phosphorus	Sodium	Magnesium	Iron	Zinc	Copper	Manganese
BARI Daruchini-1	662.67 ± 4.04b	874.67 ± 4.16a	395.33 ± 3.51b	4.65 ± 0.03b	513.66 ± 3.06c	8.11 ± 0.04b	3.07 ± 0.07c	0.75 ± 0.04a	16.45 ± 0.62b
SCZ-006	713.66 ± 3.05a	765.67 ± 3.05c	278.00 ± 2.65c	5.25 ± 0.04a	554.66 ± 4.51b	9.32 ± 0.03a	4.05 ± 0.04a	0.46 ± 0.03c	14.85 ± 0.64c
Local Daruchini	632.33 ± 2.52c	812.67 ± 2.51b	414.67 ± 1.52a	3.99 ± 0.04c	578.66 ± 1.53a	7.82 ± 0.03c	3.35 ± 0.03b	0.57 ± 0.02b	19.22 ± 0.85a
CV	0.49	0.48	0.41	0.82	0.59	0.42	1.41	1.95	1.22

Values are presented as mean ± SD (n = 3). Means with different superscripts within a row differ significantly ($p \leq 0.05$) by ANOVA and Tukey's test

Phytochemical content of cinnamon cultivars

Total phenolic content (TPC) of cinnamon cultivars

Phenolic compounds, essential plant secondary metabolites, contribute to plant defense and these are responsible for antioxidant activity. The Folin–Ciocalteu reducing assay is a widely used method to quantify total phenolic content (TPC), a key indicator of antioxidant capacity in various samples. This assay measures the formation of a blue-colored complex resulting from the reduction of the Folin–Ciocalteu reagent by phenolic compounds. The TPC of three cinnamon cultivars is presented in Table 4. The TPC of cultivar SCZ-006, BARI Daruchini-1, and local Daruchini variety barks were found to be 186.41, 163.33, and 154.57 mg GAE/100g, respectively. The results indicated that cultivar SCZ-006 had significantly higher TPC compared to the local variety (Table 4). The phenolic compound structure consists of a hydroxyl group that influences antioxidant effects on free radicals. The hydroxyl group is capable of the hydrogen donor to react with reactive oxygen species or reactive nitrogen species to block the overproduction of damaging free radicals, including peroxyl radicals, hydroxyl, and superoxide radicals (Rajan and Muraleedharan, 2017) [42]. These results align with the findings that phenolic compounds are responsible for antioxidant activity and prevent different types of diseases. Additionally, antioxidant activities are interrelated with total phenolic and flavonoid contents. Our results showed that the cultivar SCZ-006 (186.41 mg GAE/100g) had a significantly higher content of phenolic content compared to the local Daruchini variety (154.57 mg GAE/100g). Results of high phenolic content showed that a low concentration of antioxidants isolated from the cinnamon plants prevents reactive oxygen species (ROS) or reactive nitrogen species (RNS) or blocks the overproduction of damaging free radicals (Ismail *et al*. 2017) [11]. This correlation between antioxidant activity and phenolic content in cinnamon bark oil has been previously reported (Abdelwahab *et al.,* 2017; Behbahani *et al.,* 2020) [9, 28].

Table 4: Extractable phenolic, flavonoid, and antioxidant capacity of cinnamon cultivars

Variety/ cultivars	Amount in mg/100g			
	Total phenolic (mg GAE/ 100g DW)	Total flavonoids (mg QE/ 100g DW)	DPPH radical activity inhibition (%)	FRAP (mg GAE/100g)
BARI Daruchini-1	163.33 ± 1.06b	74.17 ± 0.45a	59.67 ± 0.44b	39.08 ± 0.37b
SCZ-006	186.41 ± 2.26a	69.97 ± 0.31b	53.26 ± 1.54c	34.01 ± 0.16c
Local Daruchini	154.57 ± 1.16c	66.16 ± 0.33c	67.76 ± 0.53a	41.95 ± 0.25a
CV	1.70	3.03	5.52	8.35

Values are presented as mean ± SD (n = 3). Means with different superscripts within a row differ significantly ($p \leq 0.05$) by ANOVA and Tukey's test

Total flavonoid content (TFC) of cinnamon cultivars

Flavonoids (flavonols, isoflavones, and anthocyanidins) have multiple biological effects, including antioxidant capacity. Their activity or ability to scavenge free radicals is crucial for human health. The antioxidant capacity of flavonoids is determined by their molecular structure, with hydroxyl groups playing a key role. Quercetin, a standard compound with five hydroxyl groups, exhibits potent antioxidant properties (Tsao, 2010) [43]. Consequently, high levels of phenolic and flavonoid compounds are associated with increased antioxidant capacity in plants. As presented in Table 4, our results of the TFC of BARI Daruchini-1, cultivar SCZ-006, and local Daruchini variety barks were found to be 74.17, 69.97, and 66.16 mg QE/100 g DW, respectively. Cultivar SCZ-006 exhibited the highest TFC. These findings align with previous studies by Bhagya *et al.,* 2017 [44]. Our results are very important because many polyphenols, phenolic compounds, have been reported to be strong antioxidants and suppressors of oxidative stress related damage, inhibition of lipid peroxidation, and anti-inflammatory effects. Indeed, flavonoids have been shown to possess superior antioxidant capacities compared to phenolic acids (Zhang and Tsao, 2016) [45].

Antioxidant Activities of cinnamon cultivars

DPPH radical-scavenging capacity

DPPH free radical-scavenging activity was measured in the cinnamon sample and is presented in Table 4. The DPPH content of BARI Daruchini-1, cultivar SCZ-006, and local Daruchini variety barks was found to be 59.67 %, 53.26 %, and 67.76 %, respectively. The results indicated that cultivar SCZ-006 has significantly higher inhibition activity than the local variety (Table 4). Antioxidants in the samples react with DPPH radicals, converting the purple diphenyl pyridyl-hydrazine to a colorless compound. This reduction of DPPH molecules is linked to the number of hydroxyl groups and these hydroxyl groups donate

hydrogen atoms to stabilize the DPPH radical (Samojlik *et al.* 2010) [46], and finally the results are expressed as the percentages of a reduction in the adsorption of DPPH solutions in the presence of essential oil of cinnamon. Antioxidant possible mechanisms include hydrogen atom transfer (HAT) and single electron transfer (SET) (Wang *et al.,* 2011, Apak *et al.,* 2013) [47, 48]. HAT-based mechanisms assess an antioxidant's ability to scavenge free radicals through hydrogen donation while SET-based methods detect an antioxidant's ability to transfer an electron to reduce various compounds (Dan AF, 2021) [49]. Cultivar SCZ-006 essential oil exhibited strong DPPH scavenging capacity (53.26 %), suggesting its ability to neutralize free radicals through either HAT or SET mechanisms (Al-Reza *et al.,* 2010, Aminzare *et al.,* 2018) [25, 27].

Ferric-reducing antioxidant power (FRAP) capacity

The FRAP activity assay was carried out on the cinnamon sample is presented in Table 4. The FRAP content of cultivar SCZ-006, BARI Daruchini-1, and local Daruchini variety barks were 34.01, 39.08, and 41.95 mg GAE/100 g DW, respectively. These results indicate that cultivar SCZ-006 had significantly higher inhibition capacity than the local variety (Table 4). The FRAP activity of cinnamon measures antioxidant capacity by determining the ability of a sample to reduce ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}) forms producing an intense blue color in a tripyridyltriazine complex (ferruginum) to use electron-donating antioxidants at low pH, indicating which forms an important mechanism for antioxidant capacity. Increasing the optical absorption in the mixture caused by the intensity of the blue color produced by the production of Fe^{2+} will mean increasing the reducing (antioxidant) power. Indeed, a single method's specificity and sensitivity do not ensure a reliable assessment of all types of dietary antioxidants. A single antioxidant cannot provide the same health benefits, a combination of natural phytochemical assays provides a more accurate measure of antioxidant capacity (Gohari *et al.,* 2011)[50]. Our findings show that cultivar SCZ-006 (34.01 ± 2.16 mg GAE/100 g) had a significantly higher reducing effect than the local Daruchini variety (41.95 ± 3.65 mg GAE/100 g). This suggests that the proportion number of phenolic compounds is directly involved in the antioxidant capacity of cinnamon bark (Abdelwahab *et al.,* 2017; Behbahani *et al*. 2020) [9, 28].

Conclusion

Cinnamon is worldwide used as a spice in daily life with a positive impact on human health. The comparative analysis of *C. zeylanicum* cultivars grown in Bangladesh highlights cultivar SCZ-006 as particularly notable due to its high levels of bioactive compound cinnamaldehyde (78 %), essential for aroma and flavor which are used in food processing, cosmetics, confectionaries, and medicine. Cultivar SCZ-006 also exhibited superior nutritional composition, including significant amounts of fiber, lipids, proteins, and carbohydrates compared to local varieties. The study emphasized the abundance of minerals, phytochemicals like phenolics and flavonoids, and antioxidants in cinnamon bark, contributing to its potent antioxidant properties. The present findings confirmed the antioxidant potential of the bark extract, as evidenced by its strong DPPH radical scavenging capacity. Phenolic compounds, the primary contributors to this activity, effectively neutralize free radicals through various mechanisms, thereby influencing numerous metabolic and health-related processes. Nevertheless, the antioxidant capacity of the cinnamon is due to the high presence of flavonoid and phenolic compounds. Overall, the new cultivar SCZ-006 shows promise as a nutritionally rich cultivar with potential for further development through breeding programs, scoring its versatility and health benefits in both traditional and modern applications.

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Ethical Statement

This study did not involve human and animal subjects.

CRediT authorship contribution statement

Mohammad S. Hossain: Writing–original draft, Investigation, Formal analysis, Data curation, Software, Methodology. Mohammad M. Masud: Formal analysis, Visualization, Validation, Data curation. Mohammad M. Molla: Supervision, Resources, Project administration, Conceptualization, Fund acquisition. Biddut C. Dey: Writing–review & editing, Software; Mohammad Amdadul Haque: Writing–review & editing, Software**.**

Declaration of Competing Interest

The authors declare that there is no conflict of interest (financial or non-financial) in the publication.

Data availability

Data will be made available on request.

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