

## ***In Vitro* Antioxidant Properties of Leaf and Bark Extracts of Ceylon Cinnamon (*Cinnamomum zeylanicum* Blume)**

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**ABSTRACT.** Ceylon cinnamon (*Cinnamomum zeylanicum* Blume), globally known as 'true cinnamon', is one of the oldest and most important spice crops used for culinary purposes in Sri Lanka for centuries. Although many biological activities including antioxidant properties (AP) have been reported, there are no confirmed reports whether they were originated from Ceylon cinnamon. Present study evaluates the AP of the bark and leaf extracts of Ceylon cinnamon *in vitro*. Dichloromethane: Methanol (DCM:M) and ethanol extracts of leaf and bark of Ceylon cinnamon were used in this study. The AP were evaluated using *in vitro* antioxidant assays where the total polyphenolic content (TPC), total flavonoid content (TFC) Ferric reducing antioxidant power (FRAP), DPPH radical scavenging activity, ABTS radical scavenging activity, and oxygen radical absorbance capacity (ORAC) were measured. The ethanolic extracts of both leaf and bark had significantly high antioxidant activity ( $p < 0.05$ ) compared to DCM:M extracts for all the investigated AP. The leaf ethanolic extracts had the highest TPC ( $44.57 \pm 0.51$  mg gallic acid equivalents/g), TFC ( $12.00 \pm 0.37$  mg quercetin equivalents/g), FRAP ( $125.71 \pm 3.21$  mg FeSO<sub>4</sub>/g), ABTS ( $121.78 \pm 3.20$  mg Trolox equivalents/g) and ORAC ( $44.74 \pm 0.36$  mg Trolox equivalents/g), while the ethanolic extracts of bark had the highest DPPH radical scavenging activity ( $107.69 \pm 2.01$  mg Trolox equivalents/g). Results revealed that the leaf and bark extracts of Ceylon cinnamon possess marked AP and highlight its potential use for management of oxidative stress-associated chronic diseases.

**Keywords:** Antioxidant properties, Ceylon cinnamon, *in vitro*, leaf and bark

### INTRODUCTION

Reactive oxygen species (ROS) and free transition metal ions cause extensive oxidative damage to cellular biomolecules such as DNA, proteins and lipids. Oxidation of these biomolecules often leads to oxidative stress, which can cause cell damage and contribute to aging and the development of many chronic and degenerative diseases such as cancers, coronary heart diseases, Alzheimer's disease and Parkinson's disease. Antioxidants are substances that counteract free radicals and prevent the damage caused by them. In recent years, antioxidants have gained a lot of importance due to their potential as prophylactic and therapeutic agents in many diseases. Synthetic antioxidants such as 2, 3-tert-butyl-4-methoxy phenol (BHA) and 2, 6-di-tertbutyl- 4-methyl phenol (BHT) that are widely used in the food industry have serious concerns about the carcinogenicity (Branen, 1975). Hence, in recent years plant-derived antioxidants have gained considerable interest among food scientists,

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manufactures, and consumers. Many herbs and spices, usually used to flavor dishes are an excellent source of phenolic compounds and reported to have good antioxidant activity (Rice-Evans *et al.*, 1996).

Ceylon cinnamon or true cinnamon (*Cinnamomum zeylanicum* Blume; family – Lauraceae, genus - *Cinnamomum*) is a tropical evergreen tree that grows in Sri Lanka, Madagascar, India and Indochina, and one of the oldest and most important spice crops used for culinary purposes in Sri Lanka for centuries. Cinnamon and its extract, irrespective of the source, have been associated with a variety of health beneficial effects (Anderson and Roussel, 2008).

The traditional knowledge on the use of cinnamon for a variety of diseases has been scientifically proven by many researches. *Cinnamomum zeylanicum* has been reported to have many biological activities such as being an antioxidant (Prasad *et al.*, 2009), antimicrobial and anticancer (Unlu *et al.*, 2010), anti-inflammatory (Chao *et al.*, 2008), antidiabetic (Adisakwattana *et al.*, 2011), anti-mutagenic (Jayaprakasha *et al.*, 2007) and anti-tyrosinase (Marongiu *et al.*, 2007). However, none of these activities are reported from Sri Lanka and there is no evidence for whether those are from Ceylon cinnamon, including for antioxidant activity. Limited research has also been conducted worldwide on *Cinnamomum* leaf as a natural antioxidant. Different *in vitro* antioxidant assays have been widely used to estimate the antioxidant activities of different herbs and spices (Dudonne *et al.*, 2009; Rice-Evans *et al.*, 1996). The present study evaluated the antioxidant properties of leaf and bark extracts of Ceylon cinnamon.

## MATERIALS AND METHODS

### Chemicals and equipments

Folin-Ciocalteu reagent, gallic acid, quercetin, 6-hydroxy-2-5-7-8-tetramethylchroman-2-carboxylic acid (Trolox), 1,1-diphenyl-2-picryl-hydrazyl (DPPH), 2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), potassium persulphate, 2,2'-azobis (2-amidinopropane) dihydrochloride (AAPH), sodium fluorescein, 2,4,6-tripyridyl-s-triazine (TPTZ) and 4,4'-disulfonic acid sodium salt (ferrozine) were purchased from Sigma-Aldrich (USA). All other chemicals used for the preparation of buffers and solvents were in the analytical grade. All the analyses were carried out using High-throughput 96-well micro-plate readers (SpectraMax Plus384, Molecular Devices, USA and SPECTRAMax-Gemini EM, Molecular Devices Inc, USA).

### Collection of leaf and bark samples of Ceylon cinnamon

Fresh cinnamon leaves were collected from cinnamon cultivations of L.B. Spices (Pvt) Ltd, Aluthwala, Galle, Sri Lanka. The samples were air dried at room temperature ( $25 \pm 2$  °C) for 7 days and powdered. The Alba grade cinnamon bark samples were collected from L.B. Spices (Pvt) Ltd, Aluthwala, Galle and G. P. De Silva and Sons spices (Pvt) Ltd, Ambalangoda, Sri Lanka and powdered. Powdered leaf and bark samples were stored at -20 °C for analysis of the antioxidant properties. Voucher specimen (HTS-CIN-1) and photographic evidence were deposited at the pharmacognosy laboratory of the Herbal Technology Section, Industrial Technology Institute, Sri Lanka.

### **Preparation of ethanolic leaf and bark extracts**

Powdered leaf and bark samples (20 g) were extracted into 200 ml of 95% ethanol for 4-5 hrs and 4-6 cycles in a Soxhlet extractor till the solvent in the siphon tube and extractor become colourless. The extracts were filtered and evaporated under reduced pressure, freeze dried, and stored at -20 °C for analysis of antioxidant properties.

### **Preparation of dichloromethane:methanol (DCM:M) leaf and bark extracts**

Powdered leaf and bark samples (20 g) were extracted into 200 ml of dichloromethane:methanol (1:1 v/v) at room temperature ( $25 \pm 2$  °C) for 7 days with occasional shaking. The extracts were filtered and evaporated under reduced pressure, freeze dried, and stored at -20 °C for analysis of antioxidant properties.

### **Total polyphenolic content (TPC) of cinnamon extracts**

The total phenolic content (TPC) of leaf and bark extracts of cinnamon were determined by the Folin-Ciocalteu reagent (Singleton *et al.*, 1999) using 96-well micro-plates. Twenty  $\mu$ l of 0.125 and 0.25 mg/ml of Ceylon cinnamon leaf and bark extracts were added to 110  $\mu$ l of ten-times diluted freshly prepared Folin-Ciocalteu reagent. Seventy  $\mu$ l of sodium carbonate solution was added to the mixture and incubated at room temperature ( $25 \pm 2$  °C) for 30 min and the absorbance was recorded at 765 nm. Five different concentrations of gallic acid (1, 0.5, 0.25, 0.12 and 0.06 mg/ml) were used to construct the standard curve. The TPC of Ceylon cinnamon leaf and bark extracts were expressed as mg gallic acid equivalents per gram of dry weight cinnamon leaf or bark.

### **Total flavonoid content of (TFC) cinnamon extracts**

The total flavonoid content (TFC) of Ceylon cinnamon leaf and bark extracts were determined by the aluminium chloride method (Siddhuraju and Becker, 2003) using 96-well micro-plates. One hundred  $\mu$ l of 2% aluminium chloride in methanol solution was added to 100  $\mu$ l of 0.5 mg/ml of leaf extract and 0.25 mg/ml bark extract of cinnamon in methanol. The mixture was incubated at room temperature ( $25 \pm 2$  °C) for 10 min and the absorbance was recorded at 367 nm. Pre-plate reading was recorded before adding the aluminium chloride solution. Six different concentrations of quercetin (125, 62.5, 31.25, 15.62 and 7.81 mg/ml) were used to construct the calibration curve. The TFC of cinnamon leaf and bark extracts were expressed as mg quercetin equivalents per gram of dry weight cinnamon leaf or bark.

### **Ferric reducing antioxidant power (FRAP) of cinnamon extracts**

The assay was carried out according to the method proposed by Benzie and Szeto (1999) with appropriate modifications in 96-well micro-plates (n=6). The working reagent for the ferric reducing antioxidant power (FRAP) assay was produced by mixing 300 mM acetate buffer (pH 3.6), 10 mM TPTZ solution and 20 mM  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  (10:1:1 v/v/v) just before use and heated to 37 °C. The TPTZ solution was prepared by making a solution of 10 mM TPTZ in 40 mM HCl. Reaction volume of 200  $\mu$ l containing 150  $\mu$ l working FRAP reagent, 30  $\mu$ l acetate buffer and 20  $\mu$ l of 0.5 mg/ml of leaf extract and 0.25 mg/ml of bark extract of cinnamon were incubated at room temperature ( $30 \pm 2$  °C) for 8 min and the absorbance was recorded at 600 nm. Results were expressed as mg of ferrous sulphate per gram of dry weight cinnamon leaf or bark.

**DPPH radical scavenging activity of cinnamon extracts**

The DPPH radical scavenging assay was performed according to the method described by Blois (1958) in 96-well micro-plates. Reaction volumes of 200  $\mu\text{l}$ , containing 125  $\mu\text{M}$  of DPPH radical and 50  $\mu\text{l}$  of different concentrations of leaf and bark extracts of cinnamon (leaf extracts: 0.5, 0.25, 0.125, 0.0625 and 0.03125 mg/ml, and bark extracts: 100, 80, 60, 40 and 20  $\mu\text{g/ml}$ ) were incubated at  $25 \pm 2$  °C for 15 min and the absorbance was recorded at 517 nm. Five different concentrations of Trolox (50, 25, 12.5, 6.25 and 3.125  $\mu\text{g/ml}$ ) were used to construct the standard curve. Results were expressed as Trolox equivalents antioxidant capacity in mg of Trolox per gram of dry weight cinnamon leaf or bark.

**ABTS<sup>+</sup> radical scavenging activity of cinnamon extracts**

The ABTS<sup>+</sup> radical scavenging assay was done according to the method described by Re *et al.* (1999) in 96-well micro-plates. A stable stock solution of ABTS radical cation was produced by reacting 10 mM of ABTS in potassium persulfate at 37 °C for 16 hrs in the dark. Reaction volume of 200  $\mu\text{l}$ , containing 40  $\mu\text{M}$  of ABTS<sup>+</sup> radical and 50  $\mu\text{l}$  of different concentrations of leaf and bark extracts of cinnamon (75, 50, 25, 12.5 and 6.25  $\mu\text{g/ml}$ ) were incubated at  $25 \pm 2$  °C for 10 min and the absorbance was recorded at 734 nm. Five different concentrations of Trolox (50, 25, 12.5, 6.25 and 3.12  $\mu\text{g/ml}$ ) were used to construct the standard curve. Results were expressed as Trolox equivalents antioxidant capacity in mg of Trolox per gram of dry weight cinnamon leaf or bark.

**Oxygen radical absorbance capacity (ORAC) of cinnamon extracts**

The oxygen radical absorbance capacity (ORAC) assay was carried out according to the method described by Ou *et al.* (2001) with appropriate modification in 96-well micro-plates. The assay was conducted at 37 °C and pH 7.4, with a blank sample in parallel. Trolox standards (1.5 and 0.75  $\mu\text{g/ml}$ ), fluorescein (4.8  $\mu\text{M}$ ), and AAPH (40 mg/ml) solutions were prepared prior to use in phosphate buffer (75 mM, pH 7.4). Leaf and bark samples were initially dissolved in DMSO and the DMSO concentration of the assay in blank and samples were 0.125  $\mu\text{l/ml}$ . Reaction volume of 200  $\mu\text{l}$ , containing 100  $\mu\text{l}$  of 4.8  $\mu\text{M}$  fluorescein and 50  $\mu\text{l}$  of leaf and bark extracts of cinnamon (leaf extract: 12.5  $\mu\text{g/ml}$  and bark extract: 25  $\mu\text{g/ml}$ ) were pre-incubated at 37 °C for 10 min followed by the addition of 50  $\mu\text{l}$  of AAPH (40 mg/ml) to each well to initiate the reaction. The plate was placed on the fluorescent microplate reader (SPECTRAMax-Gemini EM, Molecular Devices Inc, USA) set with excitation and emission at 494 nm and 535 nm, and the decay of fluorescein was recorded in 1 min intervals for 35 min. Trolox was used as a standard antioxidant. The ORAC activities of the samples were calculated by comparing the net area under curve of fluorescein decay between the blank and the samples. Results were expressed as ORAC values in mg of Trolox per gram of dry weight cinnamon leaf or bark.

**Data analysis**

The Softmax Pro5.2v software of the micro-plate reader (SPECTRAMaxPLUS<sup>384</sup> Molecular Devices, Inc, USA) was used to calculate the total phenol content, total flavonoid content, FARP value, percentage of radical scavenging activities of DPPH and ABTS assays, and IC<sub>50</sub> values of all cinnamon leaf and bark extracts. The Softmax Pro5.4.1v software of the fluorescent micro-plate reader (SPECTRAMax- Gemini EM, Molecular Devices Inc, USA) was used to calculate the ORAC values of all cinnamon leaf and bark extracts. For each sample of each test, three replicates were used. Data of each experiment were statistically

analyzed using SAS software version 6.12. One way analysis of variance (ANOVA) and the Duncan's Multiple Range Test (DMRT) were used to determine the differences among treatment means, and the Pearson's correlation coefficient was used for the correlation analysis ( $p=0.05$ ).

## RESULTS

The results of TPC, TFC, and FRAP, and DPPH, ABTS, ORAC antioxidant properties of ethanolic leaf and bark extracts of Ceylon cinnamon are shown in Table 1. Significant differences ( $p<0.05$ ) were observed between the ethanolic leaf and bark extracts of Ceylon cinnamon for all the investigated antioxidant properties. The ethanolic leaf extract demonstrated significantly high antioxidant activity ( $p<0.05$ ) for all the studied *in vitro* antioxidant assays except for DPPH radical scavenging activity. The DPPH and ABTS radical scavenging activities of leaf and bark extracts were dose dependent. The dose response relationship of ethanolic leaf and bark extracts for ABTS and DPPH assays are illustrated in Fig. 1, 2, and 3.

Table 2 shows the The TPC, TFC, and FRAP, and DPPH, ABTS, ORAC antioxidant properties of DCM:M leaf and bark extracts of Ceylon cinnamon. All the investigated antioxidant properties showed a significant difference ( $p<0.05$ ) between DCM:M leaf and bark extracts of the Ceylon cinnamon. The DCM:M leaf extract demonstrated a significantly high ( $p<0.05$ ) antioxidant activity for TFC, FRAP, ABTS and ORAC antioxidant properties whereas DCM:M bark extract demonstrated significantly high ( $p<0.05$ ) antioxidant activity for TPC and DPPH antioxidant assays. The radical scavenging activities of DCM:M leaf and bark extracts were dose dependant for DPPH and ABTS antioxidant assays (Fig. 1, 2 and 3).

Among the extracts used, the highest antioxidant activity was reported from the ethanolic leaf extract for all the studied *in vitro* assays including TPC, TFC, FRAP, ABTS and ORAC, except the DPPH radical scavenging activity. The ethanolic bark extract showed the highest DPPH radical scavenging activity. The order of potency of antioxidant properties for the extracts used in this study is namely, (a) for TPC: ethanolic leaf > ethanolic bark > DCM:M bark > DCM:M leaf, (b) for TFC, FRAP and ABTS: ethanolic leaf > DCM:M leaf > ethanolic bark > DCM:M bark, (c) for DPPH: ethanol bark > DCM:M bark > ethanolic leaf > DCM:M leaf, and (d) for ORAC: ethanolic leaf > ethanolic bark > DCM:M leaf > DCM:M bark. In summary, the ethanolic extracts showed a significantly higher ( $p<0.05$ ) antioxidant activity than the DCM:M extracts for all the *in vitro* assays carried out in this study.

**Table 1. Summary of antioxidant properties of ethanolic leaf and bark extracts of Ceylon cinnamon**

Cinnamon extract	Antioxidant property					
	TPC (mg gallic acid equivalents/g of cinnamon leaf/bark)	TFC (mg quercetin equivalents/g of cinnamon leaf/bark)	FRAP (mg FeSO <sub>4</sub> /g of cinnamon leaf/bark)	DPPH ( mg Trolox equivalents/g of cinnamon leaf/bark)	ABTS (mg Trolox equivalents/g of cinnamon leaf/bark)	ORAC (mg Trolox equivalents/g of cinnamon leaf/bark)
Ethanol leaf	44.57 ± 0.51 <sup>a</sup>	12.00 ± 0.37 <sup>a</sup>	125.71 ± 3.21 <sup>a</sup>	33.96 ± 0.47 <sup>b</sup>	121.78 ± 3.20 <sup>a</sup>	44.77 ± 0.36 <sup>a</sup>
Ethanol bark	33.43 ± 0.51 <sup>b</sup>	3.07 ± 0.24 <sup>b</sup>	73.02 ± 2.81 <sup>b</sup>	107.69 ± 2.01 <sup>a</sup>	89.09 ± 2.87 <sup>b</sup>	22.14 ± 1.04 <sup>b</sup>

Data represented as mean ± SE. TPC: Total polyphenolic content (n=6); TFC: Total flavonoid content (n=12); FRAP: Ferric reducing antioxidant power (n = 12); DPPH, ABTS and ORAC (n = 6). Mean within each column followed by the same letter are not significantly different at p=0.05.

**Table 2. Summary of antioxidant properties of dichloromethane: methanol leaf and bark extracts of Ceylon cinnamon**

Cinnamon extract	Antioxidant property					
	TPC (mg gallic acid equivalents/g of cinnamon leaf/bark)	TFC (mg quercetin equivalents/g of cinnamon leaf/bark)	FRAP (mg FeSO <sub>4</sub> /g of cinnamon leaf/bark)	DPPH (mg Trolox equivalents/g of cinnamon leaf/bark)	ABTS (mg Trolox equivalents/g of cinnamon leaf/bark)	ORAC (mg Trolox equivalents/g of cinnamon leaf/bark)
DCM:M leaf	20.18 ± 0.21 <sup>b</sup>	6.80 ± 0.12 <sup>a</sup>	65.17 ± 2.33 <sup>a</sup>	14.41 ± 0.98 <sup>b</sup>	113.45 ± 4.29 <sup>a</sup>	21.17 ± 0.24 <sup>a</sup>
DCM:M bark	22.91 ± 0.11 <sup>a</sup>	1.81 ± 0.14 <sup>b</sup>	44.63 ± 1.85 <sup>b</sup>	60.49 ± 0.48 <sup>a</sup>	62.88 ± 5.35 <sup>b</sup>	12.03 ± 0.36 <sup>b</sup>

Data represented as mean ± SE. TPC: Total polyphenolic content (n=6); TFC: Total flavonoid content (n=12); FRAP: Ferric reducing antioxidant power (n = 12); DPPH, ABTS and ORAC (n = 6). Mean within each column followed by the same letter are not significantly different at p=0.05.

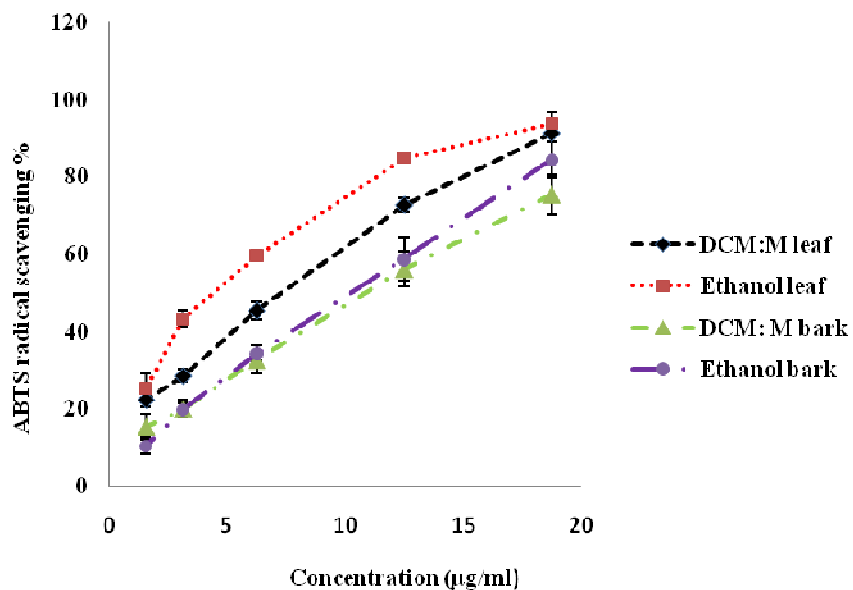


Fig. 1. Dose response relationship of ethanolic and dichloromethane:methanol leaf and bark extracts of Ceylon cinnamon for ABTS radical scavenging activity

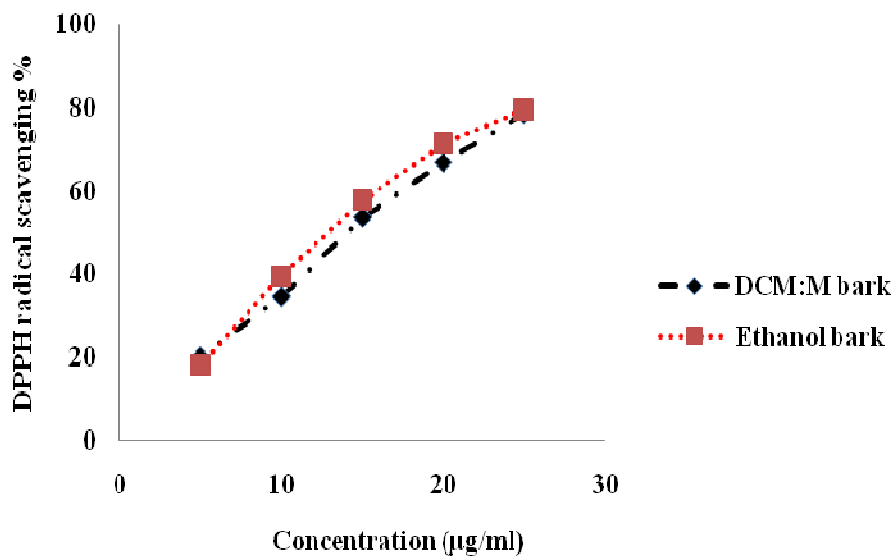
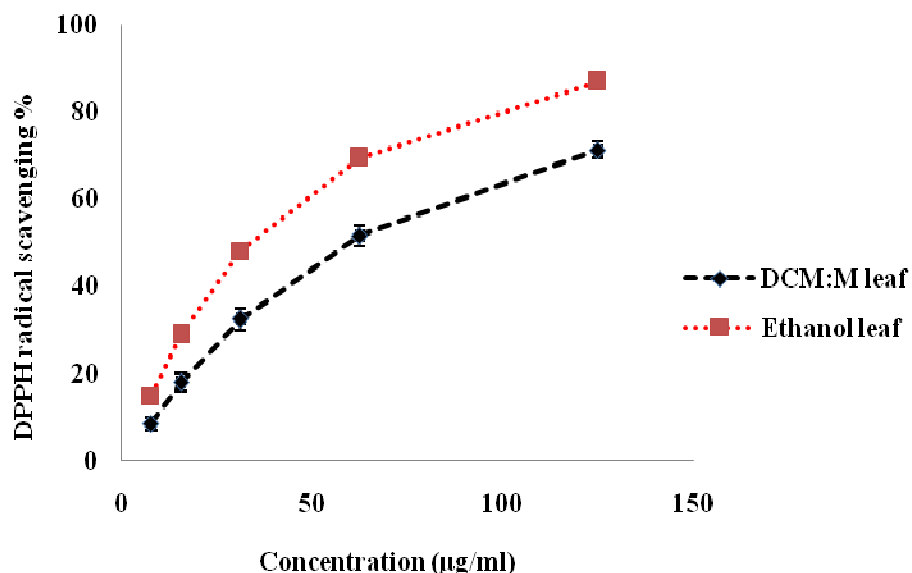


Fig. 2. Dose response relationship of ethanolic and dichloromethane: methanol bark extracts of Ceylon cinnamon for DPPH radical scavenging activity



**Fig. 3.** Dose response relationship of ethanolic and dichloromethane: methanol leaf and extracts of Ceylon cinnamon for DPPH radical scavenging activity

## DISCUSSION

Studies carried out using aqueous extracts of the leaf and bark of *C. zeylanicum* in different countries on reported of a TPC of  $2708 \pm 60.6 \mu\text{g/g}$  for cinnamon leaf (Prasad *et al.*, 2009), and for the bark, a TPC of  $309.23 \pm 0.05$  and  $200 \pm 0.05$  mg gallic acid equivalents/g of extract (Dedonne *et al.*, 2009; Adisakwattana *et al.*, 2011). In the present study similar results were observed for TPC of Ceylon cinnamon bark extracts, which was in the range of  $188.59 \pm 10.20$  to  $204.71 \pm 3.80$  mg gallic acid equivalents/g of extract. Limited research has been done on *C. zeylanicum* leaves for their antioxidant properties worldwide. In the present study, a higher TPC ( $192.83 \pm 6.31$  to  $266.28 \pm 9.97$  mg gallic acid equivalents/g of extract or  $20.18 \pm 0.70$  and  $44.57 \pm 1.70$  mg gallic acid equivalents/g of cinnamon) for leaf extract of Ceylon cinnamon was recorded, which is higher than the previously reported values. The other economically important cinnamon species such as *C. verum* and *C. cassia* have reported to possess a TPC of  $289 \pm 2.2$  and  $200 \pm 0.01$  mg gallic acid equivalents/g of extract of bark, respectively (Prasad *et al.*, 2009; Mathew and Abraham, 2006), and  $116 \pm 1.9$  mg gallic acid equivalents/g of extract of *C. verum* leaf (Mathew and Abraham, 2006). Therefore, the Ceylon cinnamon leaf has a higher TPC and more or less similar TPC in bark compared to those of other economically important cinnamon species.

As reported earlier, the TFC of leaf and bark extracts of *C. zeylanicum* was  $1075 \pm 13.8 \mu\text{g/g}$  of sample (Prasad *et al.*, 2009) and  $55.76 \pm 1.46$  mg/g of extract (Adisakwattana *et al.*, 2011). However, in the present study, the leaf extracts showed a high TFC ( $6.80 \pm 0.12$  to  $12.00 \pm 0.37$  mg/g of sample) and bark extracts had a lower TFC ( $16.1 \pm 1.22$  to  $17.26 \pm 1.24$  mg/g of



extract). The TFC of leaf extracts of *C. cassia* and *C. tamala* ( $981.1 \pm 66.6$  and  $568.1 \pm 9.7$   $\mu\text{g/g}$  of sample, respectively) have reported lower TFC, and the bark extract of *C. cassia* has shown a higher TFC ( $63.49 \pm 1.42$   $\text{mg/g}$  of extract) than *C. zeylanicum*. Therefore, the results of the present study clearly indicate that the *C. zeylanicum* leaf has a higher TPC and TFC while the bark has more or less similar values compared to those reported for other *Cinnamomum* species grown in the world.

The leaf extracts of Cinnamon demonstrated a significantly higher ABTS radical scavenging activity than the DPPH radical scavenging activity. This may be due to that the compounds with ABTS scavenging activity do not having the DPPH scavenging activity (Wang *et al.*, 1998) and other factors such as stereo selectivity of the radicals or solubility of the extract in different testing systems (Yu *et al.*, 2002). The stoichiometry of antioxidant compounds in the extract with ABTS and DPPH radicals may be different and thus, would be another reason for the difference in their scavenging potential. The DPPH radical scavenging activities of leaf extracts obtained from different species of cinnamon suggest that *C. zeylanicum* shows a higher activity than *C. cassia* and *C. tamala* (Prasad *et al.*, 2009). Mathew and Abraham (2006) reported that the ABTS radical scavenging activity of *C. verum* bark extract, at the concentration of 50  $\mu\text{g/ml}$ , was  $18.45 \pm 0.6$   $\text{mg}$  of Trolox equivalents where as the Ceylon cinnamon, at a lower concentration (14.78  $\mu\text{g/ml}$  and 13.96  $\mu\text{g/ml}$ ), showed  $60.49 \pm 0.48$  to  $107.69 \pm 2.01$   $\text{mg}$  of Trolox equivalents. hence, the Ceylon cinnamon leaf and bark extracts have higher DPPH and ABTS activity than the other important *Cinnamomum* species such as *C. cassia*, *C. tamala* and *C. verum*. Pair-wise correlations among different assays showed that the ORAC assay has the lowest correlation among other *in vitro* assays. Similar results were reported by Dedonne *et al.* (2009) for cinnamon bark extract. The discrepancy between results reported for ORAC with other assays may be due to the kinetic action of antioxidants in the ORAC than the other *in vitro* assays. Wojcikowski *et al.* (2007), reported that the ORAC value obtained from aqueous methanol extract of the bark of cinnamon is  $71.67 \pm 9.59$   $\mu\text{mol}$  Trolox equivalents/ $\text{g}$  dried sample. However, the present study reported that the ethanolic extract of Ceylon cinnamon has  $91.46 \pm 4.65$   $\mu\text{mol}$  Trolox equivalents/ $\text{g}$  dried sample.

Reducing power of the bioactive compounds is associated with the antioxidant activity. The reducing power of cinnamon leaf and bark extracts might be due to the di- and mono-hydroxyl substitutions in the aromatic ring, which possess a potent hydrogen donating abilities as described by Shimada *et al.* (1992). In general, the reducing properties are associated with the presence of reductones (Pin-Der-Duh, 1998). It is reported that the antioxidant action of reductones is based on the breaking of the free radical chain by donating a hydrogen atom, or reacting with certain precursors of peroxide to prevent peroxide formation.

In summary, the leaf and bark extracts of Ceylon cinnamon has a number of antioxidant compounds, which can effectively scavenge reactive oxygen including superoxide anions, hydroxyl radicals and as well as other free radicals. Moreover, the hydrogen donating ability of extracts has been proven through the assessment of reducing power. Considering all the extracts used in this study, the ethanolic extracts demonstrated significantly higher activity than DCM:M extracts, and the leaf extracts showed a significantly higher activity for all the assays studied including TPC, TFC, FRAP, ABTS and ORAC, except for the DPPH radical scavenging activity.

## CONCLUSIONS

The leaf and bark extracts of Ceylon cinnamon possess marked antioxidant properties, the leaf showing the highest activity. The bark of Ceylon cinnamon has more or less similar antioxidant properties reported with that of some economically important *Cinnamomum* species such as *C. cassia*, *C. tamala*, *C. verum* and *C. burmani*. The results of this study clearly indicate the potential use of leaves and bark of Ceylon cinnamon in the day-to-day life for prevention of oxidative stress-associated chronic diseases and for development of functional foods, nutraceuticals and drug discovery.

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