Onion (*Allium cepa* L.) is potentially a good source of important antioxidants

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Abstract Six different cultivars of onions available in the Kuwaiti market were analyzed for various physico-chemical properties, such as, moisture content, sugar composition, TBARS as malondialdehyde, total phenolic content, as well as trolox equivalent antioxidant capacity, these cultivars comprised of US onions white, US onions yellow, Indian onions red, Egyptian onions red, New Zealand onions golden and Saudi onions white. Layers from each onion bulb were manually cut and separated into three nearly equal portions, i.e., outer layers, middle layers and the inner layers. The outermost layers of the bulb showed the highest concentration of antioxidant compounds and a distinct decreasing trend was observed towards the innermost layers in all types of onion samples. The onion samples studied showed variations in carbohydrate contents (glucose, fructose and sucrose), which would have important implications in affecting the flavor (sweetness and pungency) and the suitability of these onions for processing. An important observation is about the distribution of antioxidant compounds with the highest contents in the outermost layers of the onions than in their middle and inner layers. Unfortunately, these outer layers are generally discarded by the consumers thus depriving them of the important health-promoting phytochemicals.

Keywords *Allium cepa* · Antioxidant capacity · Total phenolics · Sugars · Free radical scavenging activity

Introduction

Onion belongs to the genus *Allium* in Alliaceae family and contains many cultivars which are colored. Onions are the oldest cultivated vegetables, and are second only after tomatoes, both of which are extensively used not only for culinary purposes all over the world (Benitez et al. 2011). The color of red onions is primarily due to anthocyanins present in the epidermal cells of the scale leaves of the bulb, and their main anthocyanin pigment is reported to be cyanidin 3-glucoside (Fossen et al. 1996; Fossen and Andersen 2003; Lee et al. 2015).

Onion is a multi-use vegetable that is consumed fresh as salad as well as in the form of a number of processed products (Manohar et al. 2017). Regular consumption of onions has been shown to reduce the risk of cancer, cataract, DNA damage, vascular and heart diseases (Arung et al. 2011; Jimenez et al. 2011; Hamazu et al. 2011). The presence of onions and garlic in the pan-fried meat has been shown to reduce the formation of carcinogenic heterocyclic amines and azaarenes in the cooked meat samples (Janoska 2010).

The distribution of major flavonoids (e.g., quercetin derivatives) in outer, middle and inner parts of onion bulbs in Germany have recently been reported by Beesk et al. (2010). The antioxidant and free radical scavenging activities of phenolics from four types of Indian onions (red, violet, white and green) have been investigated by Prakash et al. (2007). Chopping, refrigeration, oven roasting, and frying did not have a significant reduction in flavonols and anthocyanin contents in red onions (Rodrigues

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et al. 2009). Flavonol contents in red onions significantly increased (64%) during ambient storage for 6 months, but the anthocyanin contents showed 40–60% decrease. Post-harvest UV (40 kJ/m², 1-week storage) and ethylene (100 µL/L for 24 h, 2 months storage) treatments enhanced the flavonol contents significantly (Rodrigues et al. 2010). Hot and dry meteorological conditions have been shown to enhance the flavonol contents in Portuguese cultivars of white and red onions (Rodrigues et al. 2011). The total flavonols increased by 58% and total anthocyanins by 39% in fresh-cut onions when stored in transparent polystyrene cups under visible light (Perez-Gregorio et al. 2011). The extraction method, such as, the use of microwave-assisted extraction of onion has been reported to yield the highest level of antioxidant activities (Huma et al. 2011).

Major portion of the vegetables, including onions, are being imported into Kuwait from different countries to meet the requirements of local population. Onions are consumed widely in Kuwaiti household cookery and are important constituents of the local diet. The total requirements of onions for Kuwaiti population are met by imports from many countries, such as, Egypt, India, Kingdom of Saudi Arabia, Iran, USA, Australia, and New Zealand. No data is available on the physico-chemical and antioxidant properties of onion cultivars being marketed in the State of Kuwait. As onions hold a place of significance in Kuwaiti dietary, any scientific information made available on the physico-chemical and antioxidant properties will be useful to the consumers for improving their health status by selecting the best among yellow, white and red onion cultivars.

Materials and methods

Raw materials

Six different cultivars of onions available commercially in the Kuwaiti market were collected from the local market. These samples comprised of US onions white, US onions yellow, Indian onions red, Egyptian onions red, New Zealand onions golden and Saudi onions white. Layers from each onion bulb were manually cut and separated into three nearly equal portions, i.e., outer layers (including the skins), middle layers and the inner layers. These samples were then macerated in a blender and freeze-dried (make: Virtis, model: Unitop 800 L, USA). The freeze-dried samples were coded and stored in air-tight containers at – 20 °C till further use.

Total solids

Total solid contents in the fresh as well as freeze-dried onion samples were determined by the standard AOAC

method (2005). A known weight of the onion sample was dried overnight in a hot air oven at 105 °C to achieve a constant weight. All the following chemical analyses are expressed on a moisture-free basis.

Carbohydrate analysis

The freeze-dried outer, middle and inner scales of onion samples were taken for glucose, fructose and sucrose analysis as per the method of Hudson et al. (1976). After homogenization of the sample, extraction of sugars is carried out with 80% ethanol. The extract is heated for some time and made up to the required volume. Separation and determination of the individual sugar are carried out with HPLC Shimadzu (LC 10AV) using NH₂ column (250 × 4.6 mm, 5 mm analytical column, and guard column), mobile phase acetonitrile: water (80:20) and refractive index detector (Shimadzu RI). Quantitative analysis is made using carbohydrate standards. The peak area of each component is measured and compared with that of a known standard to obtain a quantitative result.

Determination of antioxidant activity

As the various flavonoids and anthocyanins are known to possess antioxidative properties, trolox equivalent antioxidant capacity (TEAC) was measured as per the procedure reported earlier by Drobiova et al. (2009). The antioxidant assay was carried out by preparing all solutions in phosphate buffered saline (PBS) containing 5 mM phosphate buffer salts and 138 mM sodium chloride. Exactly 400 µM horse heart myoglobin was mixed with 0.244 mg/mL potassium ferricyanide in a 1:1 ratio. This mixture was purified by running it on a Sephadex G-25 packed column, loading 3.5 mL of mixture for a bed volume of 43 cm³. Myoglobin fraction started eluting after the 16 one mL fractions were collected. The absorbance of these myoglobin fractions was measured using Genesys5 spectrophotometer (LABEQUIP Ltd, Markham, Ontario, Canada). All fractions with A₄₉₀ < 0.5 were pooled together and the absorbances at 490, 560, 580, and 700 nm were measured. A₇₀₀ was used as a correction factor hence it was deducted from the A₄₉₀, A₅₆₀, A₅₈₀ readings. These corrected readings were then used for calculating the concentration of myoglobin using the following equation:

$$[\text{MetMb}] (\mu\text{M}) = 146 A_{490} - 108 A_{560} + 2.1 A_{580}$$

Trolox, which is used as the antioxidant standard, was prepared in PBS with a concentration of 2.5 mM. 1 mM H₂O₂ is used to initiate the reaction. The standard curve was prepared by diluting the Trolox solutions.

Exactly 0.50 g or 0.100 g of dried onion sample was dissolved in 1 mL of PBS buffer. Then it was centrifuged

at $7000\times g$ for 3 min to remove any particulate matter and the supernatant was used for the total antioxidant measurement assay as explained above.

Total phenolics in onions

Total phenolic content (TPC) in freeze-dried onion samples was determined by the Folin-Ciocalteu method (Singleton et al. 1999). Known weight of sample was dissolved with methanol and made up the volume up to 100 mL. Then 0.5 mL of extract solution (taken in opaque flask) was mixed with 0.5 mL of the Folin-Ciocalteu reagent and then after 2 min, 0.5 mL of 100 mg/mL of sodium carbonate solution was added and allowed to stand for 2 h. The optical density of the blue-colored solution was measured in a spectrophotometer at 765 nm. The TPC was expressed as mg gallic acid equivalent (GAE)/g from the standard curve prepared by using gallic acid.

Determination of thiobarbituric acid-reactive substances (TBARS)

The thiobarbituric acid (TBA) assay is widely used to estimate the thiobarbituric acid-reactive substances (TBARS) of lipid oxidation in various plant and food materials. TBA reacts with malondialdehyde (MDA), a product of lipid oxidation to give a red fluorescent 1:2 MDA/TBA adduct with a maximum absorbance at 532 nm. Various antioxidants are known to reduce the production of MDA in food products. Lower level of MDA production in a food product is, therefore, indicative of the higher effectiveness of an antioxidant. Measurement of MDA content was, therefore, used as an indication of the antioxidant capacity of the onions. MDA level in onion samples was measured as per the procedure suggested by Du and Bramlage (1992), and MDA was calculated as given below:

$$\text{MDA Conc : (mM/g)} = \frac{\text{Absorbance of Test} \times \text{Assay Volume (1.5 ml)} \times 10^3}{\text{Molar Extinction coefficient (1.56} \times 10^5) \times \text{Weight of Substance (g)} \times \text{Sample Vol. (0.5)}}$$

Statistical analysis

Research data were analyzed for the analysis of variance (ANOVA) with post hoc using SPSS version 20 for

Windows to examine the differences among the values (between/within the groups). The $P < 0.05$ level was selected as the level of significance. Results are the mean values $\pm$ SEM (standard error of the mean) of triplicates of the same samples.

Results and discussion

Total solids in onions

The imported onions from various countries obviously would show differences in their chemical and nutritional characteristics, as the level of various health-promoting phytochemicals in onions are known to be highly variable depending upon the cultivar, production, meteorological conditions and post-harvest practices (Rodrigues et al. 2010). The six different cultivars representing a wide variety of onions available in the Kuwaiti market (US white onions, US yellow onions, Indian red onions, Egyptian red onions, New Zealand golden onions, Saudi white onions) were collected for this study and analyzed for moisture content and the results for fresh as well as freeze-dried onion samples are presented in Table 1. The moisture content slightly, but insignificantly, decreased from the outermost towards the innermost layers. In general, the moisture content in fresh samples was found to be higher in white onions ($\sim 92\%$) than the red or yellow onions ($\sim 83\text{--}88\%$). Moisture content of the freeze-dried samples varied from 2.2 to 6.3% among the onions studied. The estimated moisture content in freeze-dried samples was made use of in presenting all the analytical results on a dry weight basis. The data in Table 1 shows that the weight of outer, middle and inner layers in freeze-dried onion samples was nearly equal, indicating an equal division of each bulb into three sections.

Total sugars in onions

The freeze-dried onion samples were analyzed by HPLC method for glucose, fructose and sucrose contents and the results are presented in Table 2. The amount and type of sugars play a significant role not only in the flavor (pungency) of onions for eating as fresh but are also important

Table 1 Physical and chemical characteristics of onions samples (Mean $\pm$ S.D.)

Cultivar	Part	Moisture content in fresh sample, % wb	Weight of freeze-dried sample, as % of total bulb	Moisture content in freeze-dried sample, % db
US Onion White	Outer layers	91.9 $\pm$ 0.6	35.8 $\pm$ 0.3	3.7 $\pm$ 0.2
	Middle layers	92.1 $\pm$ 0.5 ^c	29.7 $\pm$ 0.7 ^a	4.2 $\pm$ 0.1 ^a
	Inner layers	90.8 $\pm$ 0.6 ^{c,d}	34.5 $\pm$ 0.4 ^a	3.2 $\pm$ 0.1
US Onion Yellow	Outer layers	89.0 $\pm$ 0.6	32.6 $\pm$ 0.2	5.4 $\pm$ 0.2
	Middle layers	88.4 $\pm$ 0.4 ^c	30.8 $\pm$ 0.3 ^a	4.9 $\pm$ 0.2 ^a
	Inner layers	87.4 $\pm$ 0.4 ^{c,d}	36.6 $\pm$ 0.2 ^a	5.8 $\pm$ 0.3
Indian Onion Red	Outer layers	86.5 $\pm$ 0.6	33.9 $\pm$ 0.5	5.8 $\pm$ 0.2
	Middle layers	86.5 $\pm$ 0.3 ^c	30.6 $\pm$ 0.1 ^a	5.0 $\pm$ 0.1 ^a
	Inner layers	85.5 $\pm$ 0.3 ^{c,d}	35.5 $\pm$ 0.4 ^{b,c}	6.3 $\pm$ 0.1 ^{b,c}
Egyptian Onion Red	Outer layers	84.5 $\pm$ 0.4	35.7 $\pm$ 0.2	2.2 $\pm$ 0.0
	Middle layers	83.0 $\pm$ 0.2 ^c	30.3 $\pm$ 0.3 ^a	4.3 $\pm$ 0.3 ^a
	Inner layers	82.3 $\pm$ 0.6 ^{c,d}	34.0 $\pm$ 0.3 ^{b,c}	2.8 $\pm$ 0.1 ^{a,b}
New Zealand Onion Golden	Outer layers	88.8 $\pm$ 0.7	35.5 $\pm$ 0.5	3.7 $\pm$ 0.2
	Middle layers	88.6 $\pm$ 0.3 ^c	31.4 $\pm$ 0.2 ^a	3.4 $\pm$ 0.2 ^c
	Inner layers	87.4 $\pm$ 0.1 ^{c,d}	33.1 $\pm$ 0.4 ^{b,c}	2.7 $\pm$ 0.0 ^{a,b}
Saudi Onion White	Outer layers	92.6 $\pm$ 0.2	32.2 $\pm$ 0.2	6.2 $\pm$ 0.4
	Middle layers	91.2 $\pm$ 0.5 ^c	30.3 $\pm$ 0.1 ^a	3.2 $\pm$ 0.1 ^a
	Inner layers	89.7 $\pm$ 0.6 ^{b,c}	37.5 $\pm$ 0.7 ^{a,b}	3.5 $\pm$ 0.2 ^{a,d}

from processing point of view (Kalra et al. 1995; Simon 1995). Higher levels of reducing sugars, such as, glucose and fructose result in severe browning during frying or dehydration of onions. Sucrose along with fructose affects the flavor of fresh onions for eating as salad. US white onions (62.9%) and Saudi white onions (61.9%) were found to have higher average total sugar contents followed by New Zealand golden (54.4%), US yellow (53.8%), Indian red (39.9%) and Egyptian red onions (22.4%). Among these onion samples, no clear trend was observed in the level of average total sugar contents among the outer, middle and inner scales, though, the middle scales in most cultivars had the highest total sugar contents than the outer

or inner scales except the US white onions which had highest level (80.9%) of these sugars in the inner scales. The total sugar content in outer scales was much lower in US white, US yellow, and New Zealand golden onions than the middle or inner scales. The reducing as well as non-reducing sugar levels showed a wide variation among different layers as well as among the cultivars. Interestingly, the sucrose content was found to be higher than the reducing sugars in outer, middle and inner scales of Egyptian red onion samples. Similar results showing a wide variation in reducing as well as non-reducing sugars in some of the Indian cultivars have also been reported earlier by Dhumal et al. (2007).

Table 2 Carbohydrate analysis of onions samples (% , mean $\pm$ S.D., dry weight basis)

Cultivar	Part	Glucose	Fructose	Sucrose	Total sugars*
US Onion White	Outer layers	17.4 $\pm$ 0.2	19.0 $\pm$ 0.1	3.6 $\pm$ 0.2	40.0
	Middle layers	32.2 $\pm$ 0.5 ^a	29.0 $\pm$ 0.5 ^a	6.6 $\pm$ 0.2 ^a	67.8
	Inner layers	35.1 $\pm$ 0.5 ^{a,b}	35.1 $\pm$ 0.2 ^{a,b}	10.7 $\pm$ 0.5 ^{a,b}	80.9 (62.9)
US Onion Yellow	Outer layers	11.1 $\pm$ 0.1	11.4 $\pm$ 0.1	9.0 $\pm$ 0.1	31.5
	Middle layers	16.8 $\pm$ 0.4 ^a	14.4 $\pm$ 0.1 ^a	14.5 $\pm$ 0.3 ^a	77.2
	Inner layers	20.5 $\pm$ 0.2 ^{a,b}	15.2 $\pm$ 0.1 ^{a,b}	16.9 $\pm$ 0.2 ^{a,b}	52.6 (53.8)
Indian Onion Red	Outer layers	17.5 $\pm$ 0.2	11.6 $\pm$ 0.2	12.2 $\pm$ 0.1	41.3
	Middle layers	17.5 $\pm$ 0.2 ^c	9.3 $\pm$ 0.1 ^a	15.0 $\pm$ 0.1 ^a	42.2
	Inner layers	17.0 $\pm$ 0.2 ^c	7.4 $\pm$ 0.1 ^{a,b}	11.7 $\pm$ 0.2 ^{b,c}	36.1 (39.9)
Egyptian Onion Red	Outer layers	5.8 $\pm$ 0.1	7.8 $\pm$ 0.1	8.5 $\pm$ 0.4	22.1
	Middle layers	7.4 $\pm$ 0.1 ^a	8.5 $\pm$ 0.2 ^a	10.3 $\pm$ 0.2 ^a	26.2
	Inner layers	4.6 $\pm$ 0.2 ^{a,b}	4.7 $\pm$ 0.1 ^{a,b}	9.6 $\pm$ 0.3 ^{a,b}	18.9 (22.4)
New Zealand Onion Golden	Outer layers	13.8 $\pm$ 0.2	18.1 $\pm$ 0.4	13.2 $\pm$ 0.4	45.1
	Middle layers	18.0 $\pm$ 0.4 ^a	22.8 $\pm$ 0.7 ^a	21.5 $\pm$ 0.1 ^a	62.3
	Inner layers	19.7 $\pm$ 0.3 ^{a,d}	19.5 $\pm$ 0.3 ^{b,c}	16.7 $\pm$ 0.3 ^{a,b}	55.9 (54.4)
Saudi Onion White	Outer layers	26.2 $\pm$ 0.3	26.4 $\pm$ 0.5	5.8 $\pm$ 0.1	58.4
	Middle layers	31.2 $\pm$ 0.4 ^a	27.4 $\pm$ 0.3 ^c	9.2 $\pm$ 0.2 ^a	67.8
	Inner layers	28.6 $\pm$ 0.3 ^{a,b}	22.2 $\pm$ 0.3 ^{a,b}	8.6 $\pm$ 0.2 ^{a,d}	59.4 (61.9)

*The total of glucose + fructose + sucrose content is taken as total sugars in this table. Data in parenthesis is the average of total sugars from three layers of each cultivar of onion used in the study

^aSignificant difference from outer layer; ^b Significant Difference from middle layer; ^cNo Significant Difference from outer layer; ^dNo significant difference from middle layer

Antioxidant capacity of onions (as Trolox Equivalents)

Flavonoids and anthocyanins which are secondary metabolites commonly found in many fruits and vegetables (including onions) are responsible for the attractive color of leaves, fruits and flowers. In the last few decades, these phytochemicals have attracted the attention of health professionals mainly because of their antioxidant properties (Tasleem Jan et al. 2010; Chang et al. 2010; Bang and Kim 2010; Ongkowijoyo et al. 2018). The best described property of these compounds is the antioxidant capability towards free radicals that are produced by cells metabolism or in response to exogenous environmental factors (Leopoldini et al. 2011). The molecular basis for the antioxidant properties of these compounds is due to direct reaction with free radicals (for quenching them) and from chelation of free transition metal ions which are involved in reactions finally generating free radicals (Jovanovic et al. 1998). These free radicals can damage lipids, proteins, DNA and may cause cellular membrane peroxidation. The accumulation of free radicals has been implicated in many neurodegenerative diseases such as Parkinson disease (Schulz et al. 2000).

Considering the importance of these antioxidant compounds, total antioxidant capacity of onion samples was estimated in terms of TEAC and the results are presented in Table 3. Using the Trolox standard curve, TEAC values (as Trolox Equivalents) were calculated for various onion samples. In general, the outer layers of the Egyptian red and the US yellow onions had shown the highest values (2457.0 and 2330.4/100 g, respectively) for TEAC compared with the lowest in Saudi white onions (492.3/100 g). Interestingly, a distinct gradient in TEAC values was found between the outer, central and inner scales of all types of onion bulbs (significant at $P < 0.01$). The TEAC values for the outer scales of these onion samples ranged from 492.3 to 2457.0/100 g, for middle scales from 365.69 to 1824.91/100 g, and for inner scales from 77.01 to 980.26/100 g. The outermost layers in all types of onion samples had the highest TEAC values which showed a progressive decrease in values towards the center of onion bulbs. The lowest TEAC values in the inner scales were consistently observed in all types of onion samples. The onions, especially the outer layers are reported to be the major sources of various biologically active phytochemicals, such as phenolic acids, flavonoids, cepaenes, thiosulfinates and anthocyanins (Singh et al. 2009). Unfortunately, most consumers do discard the outermost layers of onions while

Table 3 Trolox equivalent antioxidant capacity (TEAC/100 g), total phenolic content (TPC) as mg/g gallic acid equivalent (GAE), and TBARS (as MDA mM/g) levels in different layers of *Allium cepa* cultivars expressed on dry weight basis

Cultivar	Part	TEAC(mmole/100 g)	TPC(mg/g GAE)	TBARS(mmol/g)
US Onion White	Outer layers	1019.6 ± 0.2	15.1 ± 0.2	0.12 ± 0.001
	Middle layers	613.9 ± 0.3 ^a	10.7 ± 0.3 ^a	0.19 ± 0.002 ^a
	Inner layers	77.0 ± 0.6 ^{a, b}	5.1 ± 0.6 ^{a, b}	0.22 ± 0.005 ^{a, b}
US Onion Yellow	Outer layers	2330.4 ± 0.3	20.8 ± 0.3	0.13 ± 0.003
	Middle layers	1170.5 ± 0.2 ^a	16.4 ± 0.2 ^d	0.18 ± 0.001 ^d
	Inner layers	980.3 ± 0.3 ^{a, b}	15.8 ± 0.3 ^{c, d}	0.18 ± 0.002 ^{a, b}
Indian Onion Red	Outer layers	1736.4 ± 0.1	22.2 ± 0.1	0.23 ± 0.002
	Middle layers	932.3 ± 0.1 ^a	11.6 ± 0.1 ^a	0.24 ± 0.001 ^a
	Inner layers	436.4 ± 0.4 ^{a, b}	4.7 ± 0.4 ^{a, b}	0.25 ± 0.001 ^{a, b}
Egyptian Onion Red	Outer layers	2457.0 ± 1.3	20.7 ± 1.3	0.24 ± 0.007
	Middle layers	1824.9 ± 0.6 ^a	10.5 ± 0.6 ^a	0.25 ± 0.002 ^a
	Inner layers	705.6 ± 0.3 ^{a, b}	5.2 ± 0.3 ^{a, b}	0.27 ± 0.003 ^{a, b}
Newzealand Onion Golden	Outer layers	2119.0 ± 0.3	22.6 ± 0.3	0.21 ± 0.002
	Middle layers	1200.6 ± 0.2 ^a	14.3 ± 0.2 ^a	0.21 ± 0.001 ^d
	Inner layers	922.9 ± 0.3 ^{a, b}	11.2 ± 0.3 ^{a, b}	0.24 ± 0.007 ^d
Saudi Onion White	Outer layers	492.3 ± 0.1	8.2 ± 0.4	0.15 ± 0.007
	Middle layers	365.7 ± 0.3 ^a	6.2 ± 0.3 ^d	0.16 ± 0.006 ^d
	Inner layers	193.9 ± 0.4 ^{a, b}	3.7 ± 0.1 ^{c, d}	0.18 ± 0.009 ^d

^aSignificant difference from outer layer; ^b Significant Difference from middle layer; ^cNo Significant Difference from outer layer; ^dNo significant difference from middle layer

using this vegetable either as salad or in cooking, thus losing a valuable part of the antioxidant-rich material. Similar variation about the distribution of antioxidant compounds in different types of onions and various layers of onions have been reported by a number of researchers. Perez-Gregorio et al. (2010) have reported the highest content of flavonols (280–304 mg quercetin/kg fresh weight) in red onion cultivars and lower values for flavonol content (89–101 mg quercetin/kg fresh weight) in white onion cultivars. These researchers also reported flavonol levels to be different among the small- and large-sized onions. Beesk et al. (2010) have also reported the red skinned onion cultivars to have higher flavonol content than the yellow skinned cultivars. They have also reported a variation in the distribution of total flavonol content among different parts of the onion bulb.

Total phenolics in onions

The term phenolics that encompasses nearly 8000 naturally occurring compounds, are important secondary metabolites commonly found in many plants (including onions). As these phytochemicals are reported to provide many health benefits to the humans (Leopoldini et al. 2011), their pharmacological, medicinal and biochemical properties have been extensively reviewed (Das 1990; Kandasawami

and Middleton 1994; Liobikas et al. 2016). Because the onions are known to be a rich source of these phytochemicals, the total phenolic compounds (TPC) were also estimated in all the outer-, middle- and inner-scales of onion bulbs used in this study. A standard curve for total phenolics was prepared using gallic acid as a standard and all the results for total phenolics are reported as mg/g as gallic acid equivalents (Table 3). As can be seen from this table, we observed a distinct and significantly ($P < 0.01$) decreasing gradient between the outer, middle and inner scales of all types of onion bulbs. The TPC values ranged from 8.16 to 22.63 mg/g for outer scales, 6.19–16.35 mg/g for middle scales, and 3.69–15.75 mg/g for inner scales of these onion cultivars. These results are in agreement with the data presented in this table on TEAC values in outer, middle and inner scales of onion bulbs, as the TPC are also known to exhibit strong antioxidant properties. Our data on the variations of antioxidants in yellow, white and red colored varieties of onions corroborate the research findings of earlier workers (Prakash et al. 2007; Albishi et al. 2013; Lee et al. 2015; Zhang et al. 2016; Manohar et al. 2017; Kwak et al. 2017). The phenolic content of onion bulbs has been shown to be affected by the growing conditions such as soil type, dose of fertilizers, presence of *Trichoderma* spp. in the root zones (Ortega-Garcia et al. 2015). We also found that the outer layers of red and violet

varieties were richer in total phenolics, antioxidants and free radical scavenging activity than the innermost layers. The use of phenolics from onions has been suggested in apple juice processing for obtaining juice with lower browning but higher nutritional quality (Lee et al. 2016). It has also been reported that phenolic content in stored onions on aging increases compared with the fresh ones (Sharma et al. 2017).

Thiobarbituric acid-reactive substances (TBARS)

The oxidative damage to various biomolecules, especially lipids, in a living system has been estimated by measuring the content of malondialdehyde (end-product of lipid peroxidation). Higher the lipid peroxidation level, higher will be the content of TBARS as MDA and vice versa. Any food product that is rich in antioxidant compounds will prevent the lipid peroxidation, thus a lower level of MDA content will be observed (Jia et al. 2011). This approach was employed to estimate the capability of various layers among the different types of onion samples in terms of MDA levels observed and the results are presented in Table 3. As can be seen from the data presented in this table, the level of MDA showed a distinct increasing gradient between the outer, middle and inner scales of all types of onion bulbs. Evidently, the outermost layers of onion bulbs had higher content of antioxidant compounds (Table 3) than the innermost layer, thus a lower level of lipid peroxidation was observed, giving a lower value of MDA. The MDA levels ranged from 0.118 to 0.241 mM/g in outer scales, from 0.158 to 0.248 mM/g for the middle scales, and from 0.175 to 0.269 mM/g for the inner scales of these onion cultivars. These results corroborate our other findings reported in this table (measured as TEAC values) that the outermost scales of onion bulbs are richer in antioxidant compounds than the innermost scales. This gives us one more reason not to discard the outer scales of these onion cultivars, rather these outer portions should also be utilized for culinary purposes, wherever possible.

Organo-sulfur and many phenolic compounds present in allium vegetables such as onion, garlic, leek and crucifers have recently been studied for their health-improving effects (Ramirez et al. 2017). Tomsik et al. (2017) have proposed a subcritical extraction technique using 180.92 °C, 10 min extraction time with 1.09% acidifier to obtain the highest yield of phenolic compounds from *Allium ursinum* L. A number of amino acids and their derivative having health-promoting effects have been isolated by He et al. (2018) from two Chinese herbal plant (*Allium chinense* and *Allium macrostemon*) species. Tang et al. (2017) have investigated the antidiabetic and hepatoprotective activities of the butyl alcohol fraction from methanolic extract of *Allium tuberosum*. They also

reported the antioxidant activity and their ability to inhibit the pro-inflammatory mediators. The immunomodulatory potential of *Pedicularis longiflora* and *Allium carolinianum* in alloxan-induced diabetic rats has been investigated by Yatoo et al. (2018). However, they suggested more research to study the molecular mechanism involved in this immunomodulatory response. The phytochemicals present in onion and fenugreek (*Trigonella foenum-graecum* L.) have been reported to have hepatoprotective beneficial effects in diabetic rats (Pradeep and Srinivasan 2018). More recently, the in vivo effects of *Allium cepa* L. on the selected gut microflora and intestinal histomorphology in broilers (Rahman et al. 2017), antimicrobial and antioxidant activities of various garlic genotypes (Petropoulos et al. 2018) and antioxidant/antibacterial activity of onion polysaccharides (Ma et al. 2018), neuroprotective effect of S-allyl cysteine in allium species (Escubano et al. 2018), have been reported. Evidently, the *Allium* species possess a great potential for developing functional foods based on these natural phytochemicals in the coming years.

Conclusions

The outermost layers of the bulb showed the highest antioxidant activity with a distinct decreasing trend observed towards the innermost layers in all types of onion samples. The analyses of onion samples for carbohydrate contents (glucose, fructose and sucrose), showed significant variations having important implications to affect the flavor (sweetness and pungency) and the suitability of these onions for further processing. Our data showed the distribution of antioxidant activity was the highest in the outermost layers of the onion bulbs. Unfortunately, these outer scales are generally discarded by the consumers thus depriving them of the valuable nutrients. This fact needs to be brought to the knowledge of consumers so as to take advantage of such important health-promoting phytochemicals present in the outer layers of onion bulbs.

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