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ORIGINAL PAPER

Physico-chemical, antioxidant and bioactive changes in cortex core sections of carrot (*Daucus carota* var. Pusa rudhira)

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Abstract The aim of the present study was to evaluate different portions of carrot for their nutritional and bioactive characteristics. The carrots were grouped on size basis and their individual cortex and core sections were studied for carotenoid content, antioxidant activity, phenolics, and other attributes. Identification of plant varieties with relatively higher bioactive components and nutrition is important to cope up with the challenges posed by the modern lifestyle. A thorough study of different plant products can be very helpful in visualizing and identification of such plant portions. The present investigation results depicted total carotenoids and antioxidant activity of carrot were far more superior in cortex portions of the root with an increase of about 75.9–98.6 and 78.6–81.1 %, respectively for different size group carrots. An increase in the phenolic content from 8.9 to 31.8 % within cortex portion of the root was relatively less than the augmentation shown by carotenoids and antioxidant activity. Significant differences in nutrition, optical characteristics, and texture were observed within cortex and core portions. The hardness of carrot roots in terms of puncture force considerably increased for core portions of higher size groups.

Keywords Carrot · Cortex core · Antioxidant activity · Phenolics

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Introduction

Carrot is a root crop belonging to family *Apiaceae* and is regarded as conical modification of the primary root system. The plant is herbaceous without the presence of prominent stem and is grown annually and biannually for production purposes of their roots and seeds. The crop's natural habitat is dominated by temperate regions of the globe with some tropical and subtropical areas producing an efficient share of production during the winter season. Carrot roots are among the naturally rich sources of carotenoids and are regarded as unique root sources of these isoprenoid structures mainly dominated by α- and β-carotene [1]. There has been a transitional development of color from the ancient black to modern orange and red forms. The presence of different types of carotenoids in carrot roots determine their color and predominance of pigments like carotene along with lycopene impart the root with orange and red color, respectively. Anthocyanin pigments that are part of plant phenolics are present in higher quantities within the roots of black and purple colored carrots [2]. The provitamin A activity of α- and β- carotene present in the root crop have significantly increased its consumption throughout the world with people preferring the fresh and mildly treated forms of the root.

The harvested carrots contain different sized roots that can be categorized into small, medium and large forms. The size of the carrot roots is among the important attributes of consumer preference and the consumer partiality for medium sized carrots over the larger and smaller ones is evident at the supermarket stores throughout the world. Cortex and core regions of the carrot root are its two main portions with the latter portion dominated mainly by xylem tissue whereas the former majorly by phloem. The quality of the root directly depends on the ratio of these root

portions (cortex: core) with a higher ratio corresponding to an increased quality and lower value analogous to a decrease in quality. The cortex core ratio is antagonistic with the size of root and the ratio decreases with size increase and thereby lowering down the quality of overall carrot [3, 4].

The nutritional value of the carrots is regarded high amongst fruits and vegetables and ranks seventh in overall nutrition [5]. The carrots contain appreciable quantities of nutrients, minerals and are good sources of dietary fiber. The diverse chemical compounds regarded as phytochemicals present in fruits and vegetables impart different health benefits. The preventive action of these plant chemicals is majorly attributed due to their antioxidant behavior [6, 7], that scavenge the developed free radical and singlet oxygen [8–10] produced during the metabolic pathway. The presence of phenolics in combination with carotenoids imparts the root with numerous health benefits as reported by Britton [11] and Krinsky [9]. The phytochemicals present in carrot show variation both in their structure and within varieties with black varieties possessing concentrated forms of these chemicals [12]. Carrot roots have been used in the manufacture of different processed products viz. jam, candy, halwa, juice, kheer, chips, preserve, beverages, etc. Powdered form of the roots has been used as substitution of vitamin A and fiber in various bakery and snack products [3, 13]. During any processing step a set of constraints have to be maintained in order to maximize retention of bioactive components as reported by Haq et al. [14] in dehydration of carrots. Commercial carrot dessert mix under the brand name of "Kanwal carrot dessert" has been developed by Mansoor et al. [15] is available in different regions of the country particularly in Kashmir valley.

Keeping in view the global challenges to meet out nutrition demands of people current study was focused on investigating the nutritional, bioactive, optical and textural properties of the carrot portions from different sized carrots. The literature regarding the above-mentioned characteristics of cortex core portions is currently not available and the present study was planned to explore the said area of red colored carrot variety (Pusa rudhira).

Materials and methods

The fresh carrot roots were procured from Sangrur market and were washed under the potable water. The roots were divided into three size groups based on dimensions and weight, denoted as size group one (SZ1), two (SZ2) and three (SZ3). The cortex and core portions from carrots from different size group carrots were separated by using a sharp stainless steel knife. The portions of carrots were studied for nutritional (proximate analysis), bioactive (total phenolics and carotenoids), antioxidant activity, optical and textural characteristics.

Dimensional and gravimetric properties

The different sized carrots were measured for their entire length longitudinally along with different diameters positioned at the top, middle and bottom of the root designated respectively as major, middle and minor diameter. The combination of root size and weight were used for their classification into three different groups. The varying sizes of carrot were measured for length by a digital vernier caliper and weighed on Ishida MB-150 digital balance. Ten different carrots from each size group were selected for acquiring dimensions. The true density was calculated by liquid displacement method preferably using toluene and involves dividing mass with the true volume.

Proximate analysis

The moisture of fresh and stored roots was estimated by using standard procedures of Horwitz [16] in a hot air oven maintained at 105 ± 2 °C until the constant weight of the samples was achieved. The remaining parameters of proximate analysis including protein, fat, fiber, and ash were carried out as per the standard procedures reported by Rangana [17]. The protein estimation by kjeldhal method involves taking 0.5 g of the sample for digestion in concentrated H_2SO_4 that was followed by distillation and titration. Solvent extraction in a soxhlet apparatus was used for fat extraction of the samples by hexane for 6 h allowing thorough penetration of solvent throughout the sample bed. The fiber was estimated as crude fiber by boiling the sample under reflux with 0.255 N H_2SO_4 and 0.313 N NaOH for 30 min each followed by filtration and washing. The residue transferred into a crucible was dried in a hot air oven at 110 °C until constant weight followed by igniting the carbonaceous material with a burner or muffle furnace for 20 min. A muffle furnace maintained at a temperature of 550 °C was employed for ashing of charred samples. Differential method (100 − [summation of percent estimated proximate components]) was used for calculation of carbohydrate content within samples.

Total energy (calorific value)

Determination of proximate analysis was employed for computation of energy using calorific values of carbohydrate, protein and fat. One gram of carbohydrate and protein yield an equal energy value of 4 kilo-calories (kcal) whereas 1 g of fat gives away 9 kcal of energy. Computing the total energy value requires summation of all three constituents along with their multiplication factors.

Optical properties

The hunter lab colorimeter was used for determination of color by obtaining the L* (luminosity), a* (+, red, to −, green) and b* (+, yellow to −, blue) coordinates of the system. These values were further employed for calculating hue, chroma, color difference of individual values and total color difference. The color difference of the individual L*, a* and b* values denoted as ΔL, Δa and Δb were determined by working out the individual differences between the color coordinates of different sized carrots among themselves with SZ1 as reference standard. [18]. Total color difference designated as ΔE was calculated by the following formula.

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

The chroma (C) and hue angle (H) were determined by following formulas

$$C = (a^2 + b^2)^{1/2} \quad (2)$$

$$H = \tan^{-1}(b/a) \quad (3)$$

where, L, a, and b are the three color coordinates of hunter lab optical color system.

Textural characteristics

The firmness of fruits and vegetables is mainly determined by virtue of the puncture test on the tissue. The firmness was measured by puncture test using Universal Testing Machine (*TA.XT2i* texture Analyzer) from Stable Micro Systems, Surrey, UK equipped with a load cell of 50 N by application of controlled force on the 5 mm diameter probe (P5) and force time graphs were obtained. The probe speed was adjusted to 1 mm/s before and after testing and the penetration speed was regulated to 0.5 mm/s. The lateral sides, as well as the transverse cuts of the root were punctured by the probe at the cortex and core sections and the penetration depth was regulated to 8 mm.

Total carotenoids

The estimation of bioactive components involves the determination of total carotenoids and total phenolics. The total carotenoids were determined as per the method [19] with minor modifications in sample preparation and concentration of chemicals used. A known amount of sample was macerated with acetone followed by filtration and again extracting the residue with acetone until it becomes fairly colorless. The extracts were collected in a separation flask and added with petroleum ether that results in the transfer of the carotenoids towards the lipophilic phase. The separation was enhanced by the slight addition of distilled water and the phases were allowed to separate with discarding the lower layer and re-extracting the above layer with the petroleum ether. The lipophilic layer was passed through a bed of sodium sulphate (Na_2SO_4) to remove the traces of present moisture and the volume of the extract was made up to 100 ml with petroleum ether. The sample was scanned at the UV–Vis region in a spectrophotometer and the wavelength associated with the peak of highest absorbance was employed for calculation of total carotenoids by the following formula [1].

$$Total\,carotenoids(\mu g/g) = \left(\frac{Ab \times Vol \times 10^6}{A^{1\%}_{1\,cm} \times 100}\right)/W \quad (4)$$

where Ab is optical density or absorbance, W the weight of sample and $A^{1\%}_{1\,cm}$ extinction coefficient of the solvent.

Total phenolic compounds

The phenolic compounds were estimated photometrically by using Folin-Ciocalteu method as described by Singleton and Rossi [20] with minor modifications. Five grams of weighed sample was fully macerated and extracted in methanol for 12 h with a sample to solvent ratio of 1:10. The mixture was centrifuged at 4000g for 20 min followed by filtering the mixture. The methanolic extract was stored in dark and under refrigeration until estimation period. Five hundred µl of the extract in a test tube were diluted with 1 ml distilled water and added with 500 µl of Folin-Ciocalteu reagent (FCR). After 2 min, 2 ml of 20 % saturated solution of sodium carbonate (Na_2CO_3) was added into the tube. The test tubes were allowed to stand in dark for a period of 120 min followed by measuring their optical density (OD) at 715 nm. The total phenolics were estimated by drawing the standard curve of different concentrations of gallic acid in distilled water and plotting their OD with the known concentrations.

Antioxidant activity

DPPH radical scavenging activity was used for determining the antioxidant activity of the methanolic extract as described by Faller and Fialho [21]. DPPH solution with 60 µM concentration was prepared by weighing exactly 2.35 mg of DPPH in 100 ml methanol. 100 µl of the methanolic extract in a test tube added with 3.9 ml DPPH solution were allowed to stand for radical scavenging for a period of 30 min and scanned for absorbance at 515 nm using methanol as blank. The preparation of control involves the addition of 100 µl of methanol in 3.9 ml of the DPPH solution. The antioxidant activity calculated in terms of per cent DPPH radical scavenging activity by dividing

the absorbance difference between control and sample with the absorbance of control.

$$DPPH\ radical\ scavenging\ activity(\%) = \left[1 - \frac{Sample\ Absorbance}{Control\ Absorbance}\right] \times 100 \quad (5)$$

Statistical analysis

All experimental values were expressed as mean ± standard deviation and the data obtained was evaluated with analysis of variance- one way (ANOVA) by Duncan's multiple comparison tests using Statistica10.1 software as the statistical tool. The statistically significant difference during the storage period was determined by ANOVA and correlation of depending variables was determined. All measurements were carried out in triplicates except for dimension measurements in which ten replications were taken.

Results and discussion

The different size group carrots i.e. SZ1, SZ2 and SZ3 had an average length of 13.46, 17.18 and 23.34 cm, whereas their corresponding weight was 32.23, 67.15 and 133.28 g, respectively (Table 1). Growth in the root size was associated with an increase in true densities from 984 to 1029 kg/m^3 (Table 2).

Proximate analysis

The moisture content of whole carrots ranged from 90.88 to 91.19 % with SZ1 and SZ2 accounting for former and latter, respectively. A significant difference in moisture content was observed among the portions (cortex: core) of SZ2 and SZ3 while the same of SZ1 didn't show any statistically significant difference among themselves and as a whole. The SZ2 has increased moisture content both in whole as well as portion wise with the exception of SZ1 cortex (Table 1).

The range of nutritional parameters within portions and whole carrots presented in Table 1 are in conformity with Gill and Kataria [22]; Holland et al. [23]; Hashimoto and Nagayama [24]. Studies of the same taking into account carrot size and their portions are totally absent currently in literature so their comparison with any related study is not possible. This is the first instance for such kind of a work being undertaken that diminishes the possibilities of its comparison with other references. The calorific value of carrots is presented graphically in Fig. 1. Cortex portions of all size groups have almost a constant calorific value while the same is not correct for different core portions as lower values existed for first two size groups as compared to group third. The reason for increased calorific value in SZ3 core is due to significant increase in its carbohydrate, protein and fat content (Table 1).

A gradual increase in fiber content from 0.85 to 0.95 % is observed in carrots upon size increment with the former and latter related to SZ1 and SZ3, respectively. The increased true density in higher sized carrots is an indication for the development of compact tissue preferably fiber within the structure. Size of the agricultural produce is one of the criteria associated with the growth of the root crop and its increased growth is known to accumulate large fractions of the fiber that are associated with decreased quality of the root crop [25]. The fiber content in each size

Table 1 Nutritional and calorific value of *Daucus carota* var. Pusa rudhira size groups

Carrot size groups	Moisture (%)	Carbohydrates (%)	Protein (%)	Fat (%)	Fiber (%)	Ash (%)
SZ1						
Cortex	90.911 ± 0.13^{bc}	6.707 ± 0.27^{a}	0.405 ± 0.01^{cd}	0.399 ± 0.01^{bcd}	0.711 ± 0.03^{h}	0.818 ± 0.02^{ce}
Core	90.850 ± 0.03^{cde}	6.014 ± 0.17^{b}	0.364 ± 0.01^{fg}	0.338 ± 0.02^{f}	0.990 ± 0.03^{c}	0.748 ± 0.04^{f}
Whole	90.880 ± 0.08^{cde}	6.361 ± 0.06^{ab}	0.384 ± 0.00^{ef}	0.369 ± 0.01^{g}	0.851 ± 0.03^{f}	0.783 ± 0.02^{def}
SZ2						
Cortex	90.820 ± 0.29^{de}	6.619 ± 0.29^{a}	0.464 ± 0.02^{a}	0.424 ± 0.00^{a}	0.753 ± 0.00^{g}	0.842 ± 0.02^{bc}
Core	91.572 ± 0.27^{a}	5.659 ± 0.29^{c}	0.424 ± 0.01^{ab}	0.408 ± 0.01^{ab}	1.032 ± 0.02^{b}	0.830 ± 0.04^{cd}
Whole	91.196 ± 0.02^{bc}	6.139 ± 0.01^{b}	0.384 ± 0.01^{ad}	0.416 ± 0.01^{ad}	0.893 ± 0.01^{e}	0.836 ± 0.03^{c}
SZ3						
Cortex	90.776 ± 0.30^{de}	6.613 ± 0.12^{a}	0.473 ± 0.04^{ac}	0.425 ± 0.01^{ac}	0.753 ± 0.02^{g}	0.917 ± 0.02^{a}
Core	91.251 ± 0.21^{ab}	6.529 ± 0.04^{a}	0.418 ± 0.02^{cde}	0.344 ± 0.06^{cde}	1.136 ± 0.00^{a}	0.891 ± 0.02^{ab}
Whole	91.014 ± 0.05^{bd}	6.571 ± 0.08^{a}	0.445 ± 0.01^{ef}	0.385 ± 0.04^{ef}	0.945 ± 0.01^{d}	0.904 ± 0.02^{a}

Values represent mean ± standard deviation with different superscript along the column denoting a significant statistical different at $p < 0.5$ level. SZ1, SZ2 and SZ3 denote size group 1, 2 and 3, respectively

Table 2 Physical and optical properties of *Daucus carota* var. Pusa rudhira size groups

Physical parameters			Carrot size groups		Optical parameters							
Length (cm)	Weight (g)	T.D (kg/m^3)			L	a	b	Chroma	Hue^o	ΔL	Δa	Δb	ΔE
13.46 ± 1.75^c	32.23 ± 2.78^c	983.97 ± 9.74^c	SZ1	Cx	36.67 ± 2.08^d	41.33 ± 4.04^{bc}	24.33 ± 0.58^b	47.99 ± 3.53^{bc}	30.60 ± 2.45^c	NA	NA	NA	NA
				Co	58.00 ± 2.00^a	6.67 ± 4.51^f	21.00 ± 2.65^c	22.41 ± 1.50	71.96 ± 12.70^a	NA	NA	NA	NA
				Wh	41.00 ± 2.65^c	30.67 ± 3.79^d	19.33 ± 2.52^{cd}	35.57 ± 3.75^d	30.53 ± 1.78^c	NA	NA	NA	NA
17.18 ± 2.16^b	67.15 ± 11.22^b	1007.10 ± 8.19^b	SZ2	Cx	40.00 ± 1.00^c	47.67 ± 1.53^a	29.67 ± 2.52^a	56.19 ± 1.20^a	31.89 ± 2.76^c	3.33^a	6.34^b	5.34^b	9.21^c
				Co	55.67 ± 1.53^b	9.33 ± 4.16^{ef}	29.00 ± 4.00^a	30.74 ± 2.83^d	71.81 ± 9.63^a	−2.33^d	2.66^c	8.00^a	9.80^{bc}
				Wh	40.67 ± 2.31^c	41.66 ± 3.06^{bc}	24.00 ± 4.36^{bc}	48.15 ± 4.37^{bc}	29.79 ± 3.70^{cd}	−0.33^c	10.99^a	4.67^{bc}	11.19^b
23.34 ± 1.54^a	133.28 ± 25.98^a	1029.45 ± 10.17^a	SZ3	Cx	38.00 ± 2.65^{cd}	44.33 ± 3.06^b	27.67 ± 6.81^{ab}	52.39 ± 5.87^{ab}	31.60 ± 5.19^c	1.33^b	3.00^c	3.34^c	7.72^d
				Co	55.67 ± 5.03^b	11.67 ± 5.13^e	17.67 ± 2.08^d	21.42 ± 3.86^e	57.60 ± 11.22^b	−2.33^d	5.00^{bc}	−3.33^e	8.45^{cd}
				Wh	32.67 ± 2.08^e	40.67 ± 6.66^c	20.67 ± 0.58^c	45.71 ± 5.71^c	27.32 ± 4.53^d	−8.33^e	10.00^a	1.34^d	14.01^a

Values represent mean ± standard deviation with different superscript along the column denoting a significant statistical different at $p < 0.5$ level

T.D true density, *SZ* size group, *Cx* cortex, *Co* core, *Wh* whole

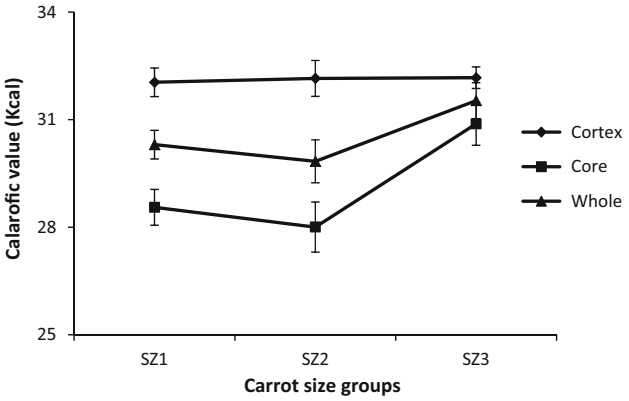

Fig. 1 Comparison of calorific value from carrot portions and whole carrots with respect to their size

group is dominated by the core with an increasing trend similar to the whole carrot (Table 1). A similar trend is observed for the ash content that increases with the increase in size and the reason may be its increased growth resulting in accumulation of more minerals from the soil mainly dominated in the cortex portion of the root. There is a slight increase of carbohydrate, protein and fat content in cortex regions of carrots from different size groups. Whole carrots of SZ3 have the highest percentage of carbohydrate and protein whereas SZ2 has the highest amount of fat within their tissues. The high percentage of fiber in SZ3 coupled with low cortex core ratio significantly decreases the marketability and consumer preference of these carrots [4]. The SZ2 carrots are superior in quality and nutrition compared to other two types and is first choice of consumer preference in the market.

Optical properties

The different parameters of the optical property did not show an evident difference between the different size groups except for the L (lightness) values. The L*, a*, b*, hue and chroma values are presented in Table 2 along with the color difference of first three values for SZ2 and SZ3 with respect to SZ1. The positive values of ΔL, Δa and Δb are associated with more lightish, reddish and yellowish tings, respectively and vice versa [18]. The positive values of Δa for SZ2 and SZ3 denote a more reddish colored sample than the reference (SZ1) with whole carrot showing more difference than the individual portions. The negative values of ΔL in whole carrots were expected due to compaction of plant metabolites and carotenogenesis of the roots during increased growth. The hue angle of 0° and 90° are respectively related to redness and yellowness colors and a hue angle closer to 0° denotes more reddish colored product. The hue angle also confirms the lesser reddish color of SZ2 and SZ3 than SZ1as predicted by a* value.

The total color difference (ΔE) with value <1.5 denotes a very small color difference while as the values from 1.5 to 3 and >3 signify a distinct and very distinct color difference, respectively [26]. The hue angle increased from 28.74° to 36.74° upon storage while as its 'a*' values decreased significantly from 38.8 to 27.5 denoting a gradual decrease of red the hue towards the yellow. The hue angle 0° or 360° indicate a red colored entity and the yellow color is represented by the angle of 90°. The range of the hue below the 45° mark confirms the predominance of reddish color over the yellow with overall reddish-yellow color (Table 2).

Textural characteristics

Firmness or hardness of carrot is an important attribute to govern its quality among consumers. The carrot is naturally categorized as a hard product that must have a crunchy structure in order to retain its acceptability [27]. Puncture and compression come under the empirical tests that are widely used in evaluating the textural properties by application of the deforming forces [28–30]. The results of the puncture test show firmness values are significantly high for core with SZ3 possessing the highest values [31, 32]. The firmness values of the cortex are almost constant except for SZ1 showing a little decline in puncture force (Fig. 2). The presence of increased amounts of fiber raises penetration force that directly affects the root tenderness.

Total carotenoids

A significant difference in total carotenoids was observed among the portions as well as in whole carrots of each group with cortex proving to be a much richer source of the said component (Table 3). The presence of total carotenoids in the core was as low as 1.4–24 % (Fig. 3) in comparison to their corresponding cortex regions with the former and later values related to SZ1 and SZ3, respectively. Total carotenoid levels of SZ1 showed a statistically significant difference with the roots of SZ2 and SZ3. The relative increase of carotenoids in roots of SZ2 and SZ3 is an example of increased carotenogenesis that results in the transformation of glyceraldehyde-3-phosphate to carotenoids. Increase in the red color of root can be attributed to increasing carotenoid levels [33] as evident from 'a*' value. Bozalan and Karadeniz, [34] reported a strong positive correlation between total carotenoids and antioxidant activity while examining the carotenoid profile of carrots. The results of the present study were consistent with various previous studies [5, 34–36].

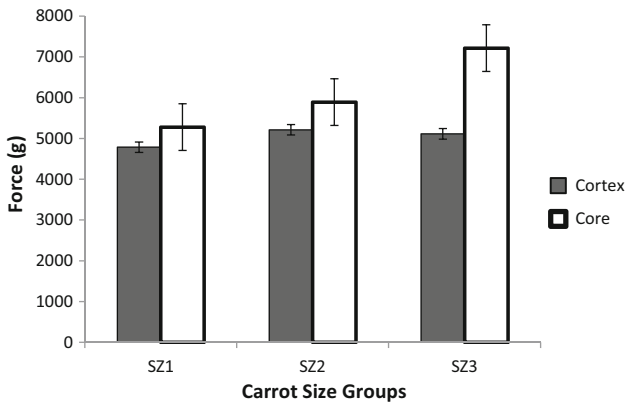

Fig. 2 Puncture test results of cortex and core portions from different size group carrots

Total phenolics

The presence of phenolics within cortex core regions of the root had a statistically significant difference in all size groups. The difference was limited only to SZ1 in case of whole carrots whereas both SZ2 and SZ3 didn't show any significant difference. The highest amount of phenolic content was present in cortex and core portions of SZ2 and SZ3 with relative values of 53.12 and 42.31 mg/100 g, respectively (Table 3). The phenolic deficit of core with respect to its corresponding cortex was highest (32 %) for SZ2 and lowest (8 %) for SZ1. Similar case was reported for the whole carrot in relation to cortex whose deficit levels ranged from 4 to 16 % with SZ2 dominating the deficiency levels than SZ1 and SZ3 (Fig. 1). Overall an increase of about 14 and 13.4 % was found in whole SZ2 and SZ3 carrots with respect to SZ1. The overall phenolic range in carrots was in agreement with the studies of Leja et al. [37] and Kaur and Kapoor [38] for different cultivars of carrots and some Asian vegetables, respectively. Bozalan and Karadeniz [34] reported the phenolic range of 11.4 to 30.6 mg *catechin*/100 g within different forms of carrot.

Antioxidant activity

The changes related to antioxidant activity in different carrot portions are presented in Table 3. The lower DPPH radical scavenging activity observed in core portion continues for all size groups and a decreased activity of about 19–22 % with respect to their core portions is seen (Fig. 3). The antioxidant activity ranged from 5.12 to 29.64 % with lower and higher values representing the activity of core and cortex, respectively. The carrot roots of SZ2 had higher antioxidant activity than the minor and major sized carrots. Significantly lower amounts of bioactive components within the core portion confer deficit

Table 3 Carrot bioactive components and their antioxidant activity

Carrot size groups	Total phenolics (mg GAE/100 g)	Total carotenoids (mg/100 g)	Total antioxidant activity (%)
SZ1			
Cortex	42.284 ± 1.46^{cd}	19.246 ± 2.05^{c}	24.131 ± 2.01^{b}
Core	35.987 ± 1.39^{f}	0.262 ± 0.06^{g}	5.156 ± 1.55^{d}
Whole	39.136 ± 0.40^{e}	9.754 ± 1.00^{e}	14.643 ± 1.53^{e}
SZ2			
Cortex	53.118 ± 2.43^{a}	28.023 ± 1.33^{a}	29.638 ± 1.28^{a}
Core	36.232 ± 0.69^{f}	1.784 ± 0.19^{g}	6.397 ± 1.72^{d}
Whole	44.675 ± 1.30^{bc}	14.903 ± 0.68^{d}	18.018 ± 1.50^{c}
SZ3			
Cortex	46.453 ± 1.51^{b}	25.343 ± 1.60^{b}	29.027 ± 0.65^{a}
Core	42.314 ± 0.89^{cd}	6.101 ± 0.90^{f}	5.487 ± 1.05^{d}
Whole	44.383 ± 1.11^{bd}	15.722 ± 0.70^{d}	17.257 ± 0.62^{c}

Values represent mean ± standard deviation with different superscript along the column denoting a significant statistical different at $p < 0.5$ level

GAE gallic acid equivalent

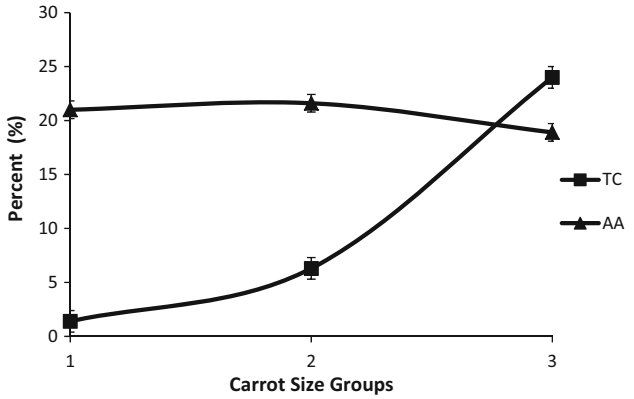

Fig. 3 Depiction of total carotenoid and antioxidant activity levels (%) within core portion of carrot with respect to their cortex from different sized carrots

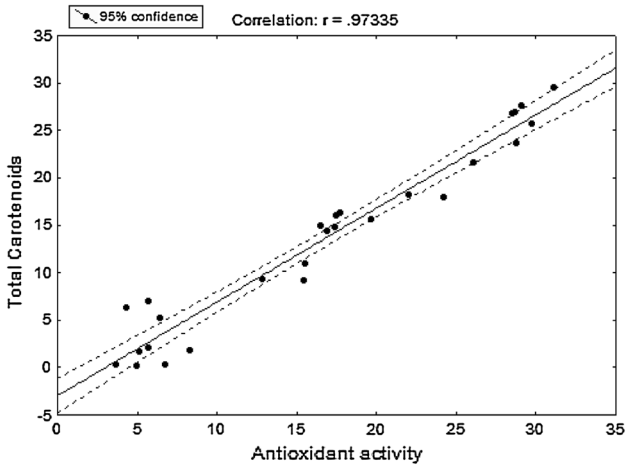

Fig. 4 *Scatter plot* of antioxidant activity versus total carotenoids for estimating their correlation

antioxidant activity to it. Antioxidants show a positive correlation [34, 38], and linear relation [39, 40] with phenolic content but the same was not found by Heinonen et al. [41]; Gazzani et al. [42]; and Kahkonen et al. [43]. A strong positive correlation existed between antioxidant activity and total carotenoids with correlation coefficient '*r*' equals to 0.97 (Fig. 4) whereas formers correlation with phenolic components was medium with '*r*' value of 0.79 (Fig. 5). The bioactive components are mainly associated with imparting antioxidant activity in addition to other health promoting benefits. Both carotenoid and phenolics are potent antioxidants that scavenge the generated free radicals. Antioxidant activities of different plant metabolites are due to their redox properties enabling them to quench singlet oxygen and free radicals, act as hydrogen donors and metal chelators [44].

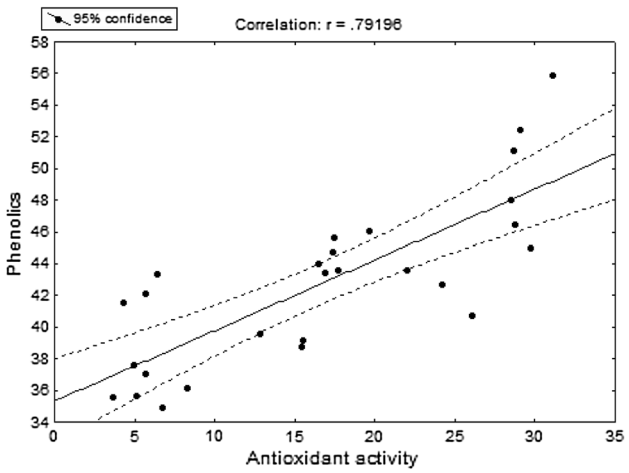

Fig. 5 *Scatter plot* of antioxidant activity versus phenolics for estimating their correlation

Conclusion

Carrots are undoubtedly nutritionally rich food sources and the results of current study showed increased amounts of bioactive components in cortex portion of the roots with SZ2 as relatively richer source amongst all. A gradual increase in the plant metabolites within core portions was observed in higher size group roots. The free radical scavenging power of SZ2 carrots was superior as compared to other carrot groups due to the presence of more bioactive components within the cellular matrix. The carrots of SZ3 were slightly more nutritious than other two groups, but a lower cortex core ratio spoils their presence within the root rendering them least acceptable for human consumption. The total color difference of whole carrot as well as their portions was by far very distinct with respect to SZ1. The results revealed that SZ2 or medium sized carrots with a higher cortex core ratio are nutritionally and chemically superior to other forms of roots. A linear, strong and positive correlation was found between total carotenoids and antioxidant activity indicating latter's dependence more on former in comparison to total phenols.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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