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Peel and flesh antioxidant content and harvest quality characteristics of seven apple cultivars

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Abstract

The variation in the antioxidant content and the associations that may exist with harvest quality characteristics in peel and flesh tissue from seven apple cultivars were studied. Total antioxidant activity, total phenolic and ascorbic acid content, total soluble solids, total acidity and color parameters were measured in flesh and peel fruit tissues from the apple cultivars Fuji, Golden Delicious, Granny Smith, Jonagored, Mutsu, Starkrimson and Fyriki. In flesh tissue, Fyriki contained the highest antioxidant activity and total phenolic content (up to 82% and 67% more, respectively), while the lowest values were found in Fuji, Golden Delicious and Granny Smith. The ascorbic acid content was also greatest in the flesh tissue of Fyriki (up to 36% more). In peel tissue, the greatest antioxidant activity and total phenolic content were found in Starkrimson (up to 64% more) whereas the lowest values were found in Golden Delicious and Granny Smith. Apple peel contain from 1.5 to 9.2 times greater total antioxidant activity and from 1.2 to 3.3 times greater total phenolic content compared with flesh. Principal component analysis and correlation analysis showed that a more nutritious peel may be darker, redder and bluer, while a more nutritious flesh may have a lighter color and lower soluble solid content. It is concluded that Starkimson and the local cultivar Fyriki should be regarded as a valuable source of antioxidants, while fruit harvest quality characteristics may suggest for nutritional properties of apple.

Keywords: Antioxidant activity; Ascorbic acid; Fruit color; Soluble solids content; Total acid; Total phenolics

1. Introduction

Apple consumption has been associated with the prevention of cancer and coronary heart diseases (Knekt et al., 1997; Le Marchand et al., 2000) which are the main causes of death in developed countries. Apple is a favored fruit for the European and North American citizens. It constitutes 22% of fruit phenolics consumed in the United States of America being the largest contributor (Vinson et al., 2001) and the first and the third contributor of flavonoids in Finish and Dutch diet, respectively (Hertog et al., 1993; Knekt et al., 1997).

The polyphenolic antioxidants contained in apples are responsible for most of the antioxidant activities of the fruit (Lee et al., 2003). Apples also contain ascorbic acid but explain less than 0.4% of the antioxidant activity, indicating that other factors, such as phenolics, are the main contributors (Eberhardt et al., 2000). The content of polyphenolic compounds is particularly high in the peel, compared with the flesh or cores of apples (Wolfe et al., 2003; Tsao et al., 2003).

Recent studies have shown that the apple cultivar may substantially influence the fruit phenolic content, total antioxidant activity (Imeh and Khokhar, 2002; Lee et al., 2003; Vrhovsek et al., 2004) and the ascorbic acid content (Schmitz-Eiberger et al., 2003; Planchon et al., 2004). Great variation also occurs in the harvest quality characteristics of different apple cultivars exhibiting red, yellow, green or bicolored peel and the flesh may have more or less bright coloration and variable sugar and acid content. Little attention has been given on examining whether there are associations between the fruit harvest quality characteristics and antioxidant content as this would have been an important information to the consumer to recognize a more nutritional fruit. Interesting associations were found in the pomegranate fruit suggesting that small sized and red colored pomegranates may be more nutritious (Drogoudi et al., 2005).

The objectives of the present study were: (a) to describe the variability in the concentration of bioactive compounds in the peel and flesh tissue from six apple cultivars which are

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commercially important worldwide and one apple cultivar widely grown in Greece, and (b) to find whether there are associations between the apple harvest quality characteristics and antioxidant content.

2. Materials and methods

Fruit from the cultivars Fuji, Golden Delicious, Granny Smith, Jonagored, Mutsu, Starkrimson and Fyriki were harvested from an experimental orchard at the Pomology Institute, Naoussa, Greece at commercial maturity. The fruit peel and flesh color L^* (brightness or lightness; 0 = black, 100 = white), a^* ($-a^*$ = greenness, $+a^*$ = redness) and b^* ($-b^*$ = blueness, $+b^*$ = yellowness) dimensions were measured in six fruit replicates, using the chromatometer Minolta (Minolta, Ramsey, NJ).

2.1. Chemical analyses

At harvest soluble solid content (SSC) and total acidity (TA) were determined in juice extracted using a food processor in three replicates of two apples. SSC was measured using a digital refractometer (model PR-1, Atago, Japan), and TA by titration to pH 8.2 with 0.1 N NaOH and expressed as malic acid content (g 1 L^{-1}).

Upon harvest six fruit per cultivar were washed with distilled water, towel dried and frozen at −20 °C. In frozen fruit, the peel and flesh were scraped using a knife, dried to constant weight in a freeze drier, ground using a pestle and mortar and stored at −20 °C until chemical analyses were performed within a 3-month period.

Chemicals were purchased from Sigma Chemical Co (St. Louis, MO). Assays were performed using an automated UV/visible spectrophotometer.

2.2. Extraction procedure

Four hundred gram DW were homogenized with 10 mL of 80% MeOH/H_2O (v/v) at 2000 rpm in a micro-dismembranator (B. Braun Biotech Intern., Melsungen, Germany). The samples were centrifuged for 10 min at 5000 × *g* at 5 °C and immediately assays for total phenol content and antioxidant activity were performed in the supernatant recovered. Extractions were made in three replicates of a composite sample made from six fruit.

2.3. Total phenolic and antioxidant activity assays

Total soluble phenolics were determined with the Folin–Ciocalteu reagent and results were expressed as mg gallic acid 100 mL^{-1}.

Antioxidant activity was measured using the stable 1,1-diphenyl-2-picryl hydrazyl (DPPH) free radical (Blios, 1958), which has an intense violet color, but turns colorless as unpaired electrons are sequestered by antioxidants. Reaction mixtures containing 0 or 20 μL sample and 2300 μL of 106.5 μM DPPH in MeOH and 680 μL H_2O, were vortexed, and then held at room temperature for 2 h. The absorbances of the reaction mixtures were measured at 517 nm and AEAC (mM) was extrapolated from a standard curve prepared using 0–2.7 mM ascorbate (ASC) ($y = x^*6088.9$; $r^2 = 0.996$; $P < 0.001$).

2.4. Ascorbic acid assay

Ascorbic acid was determined only in flesh tissue, using the reflectometer Merck RQflex. About 2 g of frozen fresh tissue were extracted in 3 mL of ice-cold 6% (w/v) metaphosphoric acid containing 0.2 mM ETDA. The extract was centrifuged at 15,000 × *g* for 7 min at 4 °C and the ascorbate content was measured. Results were expressed as mg ASC 100 mL^{-1}.

2.4.1. Statistical analysis

Analysis of variance, correlation analysis, principal component analysis (PCA) and between group linkage cluster analysis using the method of squared Euclidean distance, were performed using SPSS (SPSS Inc., Chicago, Illinois, USA). LSD values were calculated in cases that significant variance was found at $P \leq 0.05$.

3. Results and discussion

In peel tissue, the highest antioxidant activity (35.7 ± 0.9 mg g^{-1} DW mean ± S.E.) and total phenolic content (19.9 ± 0.6 mg g^{-1} DW) were found in Starkrimson, followed by Jonagored, Mutsu, Fyriki and Fuji (mean values 19.9 ± 0.4 and 12.9 ± 0.4 mg g^{-1} DW, respectively), whereas the lowest values were found in Golden Delicious and Granny Smith (13.8 ± 0.5 and 8.4 ± 0.5 mg g^{-1} DW, respectively) (Fig. 1). In the flesh tissue, the greatest antioxidant activity and total phenolic content were found in Fyriki (11.9 ± 0.7 and 9.8 ± 0.5 mg g^{-1} DW, respectively), followed by Jonagored, Mutsu and Starkinson (5.6 ± 0.2 and 5.4 ± 0.4 mg g^{-1} DW, respectively) and the lowest contents were found in Fuji, Golden Delicious and Granny Smith (3.7 ± 0.1 and 3.5 ± 0.4 mg g^{-1} DW, respectively). The flesh of Fyriki gets a brown coloration quickly once cut into slices, which may be attributed to the high content of phenolic compounds contained. Fyriki has a distinctive pleasant aroma and is widely used as a pollinator tree in apple orchards in Greece.

Comparison of the total phenolic content values obtained in this study with those of other studies suggests similar results although differences in the units reported and spectophotometric standards employed make a direct comparison difficult. Kahkonen et al. (1999) reported 12 mg GAE 100 g^{-1} DW in flesh of unspecified cultivar. A similar trend in the total phenolic content of edible apple portions (peel and flesh) was found among the studied cultivars by Imeh and Khokhar (2002) and Vrhovsek et al. (2004).

The ascorbic acid content in flesh was greatest in Fyriki (4.4 ± 0.2 mg 100 g^{-1} FW) compared with the rest cultivars which did not differ in between (3.1 ± 0.1 mg 100 g^{-1} FW). Mean values of ascorbic acid content were at the lower range of those reported for other commercial apple cultivars by

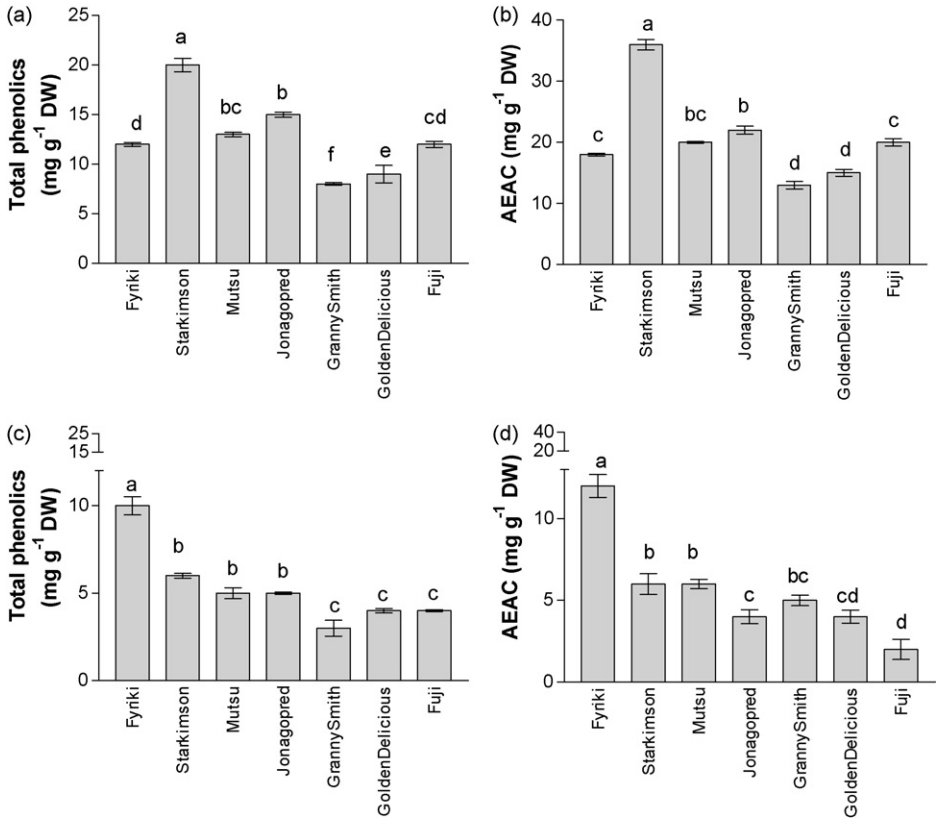

Fig. 1. Total phenolic content (mg gallic acid g^{-1} dry weight) (a and c) and total antioxidant activity (AEAC) (mg ascorbic acid g^{-1} dry weight) (b and d) in peel (a and b) and flesh (c and d) tissues of seven apple cultivars. Values represent mean ± S.E. Different letters denote significant differences ($P \leq 0.05$); values bearing the same superscript are not significant different from one another.

Planchon et al. (2004) (2.9–12.3 mg 100 g^{-1} FW), and this may be attributed to the different analytical method employed.

Ascorbic acid content was positively correlated with antioxidant activity ($r = 0.749$), while a better correlation was found between the total phenolic and total antioxidant activity in the flesh and peel tissues ($r = 0.914$ and 0.977, respectively), suggesting that phenols have a more significant contribution to the total antioxidant capacity of apples (Table 1). Lee et al. (2003) found that flavonoids such as quercetin, epicatechin and perocyanidin B2 rather than ascorbic acid contribute significantly to the total antioxidant activity of apples.

Apple peel contain from 1.5 to 9.2 times greater total antioxidant activity and from 1.2 to 3.3 times greater total phenolic content compared with flesh, with lower values found in Fyriki and higher in Fuji, respectively (Fig. 1), suggesting that peel removal may induce a more significant nutrient losses in some cultivars than others. Higher concentration of phenolic compounds in peel than flesh was also reported by other

Table 1
Correlation coefficients of color parameters (L, a^* and b^*), total soluble solids (TSS), total acids, total phenols (TPh), antioxidant capacity (AEAC) and ascorbic acid content in peel and flesh tissue of apples

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Peel – L	1												
2. Peel – a^*	**−0.887**	1											
3. Peel – b^*	**0.940**	**−0.906**	1										
4. Flesh – L	ns	ns	ns	1									
5. Flesh – a^*	ns	ns	ns	ns	1								
6. Flesh – b^*	ns	ns	ns	ns	ns	1							
7. Flesh – TSS	ns	ns	ns	ns	ns	ns	1						
8. Flesh – total acids	ns	−0.760	ns	ns	ns	ns	ns	1					
9. Peel – TPh	ns	ns	**−0.826**	ns	ns	ns	ns	ns	1				
10. Peel – AEAC	−0.783	ns	**−0.860**	ns	ns	ns	ns	ns	**0.977**	1			
11. Flesh – TPh.	ns	ns	ns	ns	ns	ns	ns	−0.751	ns	ns	1		
12. Flesh – AEAC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**0.914**	1	
13. Flesh – ascorbic acid	ns	ns	ns	ns	ns	ns	ns	−0.748	ns	ns	0.757	0.749	1

ns, non significant. Absolute linear correlations ≥ |0.80| are marked in bold.

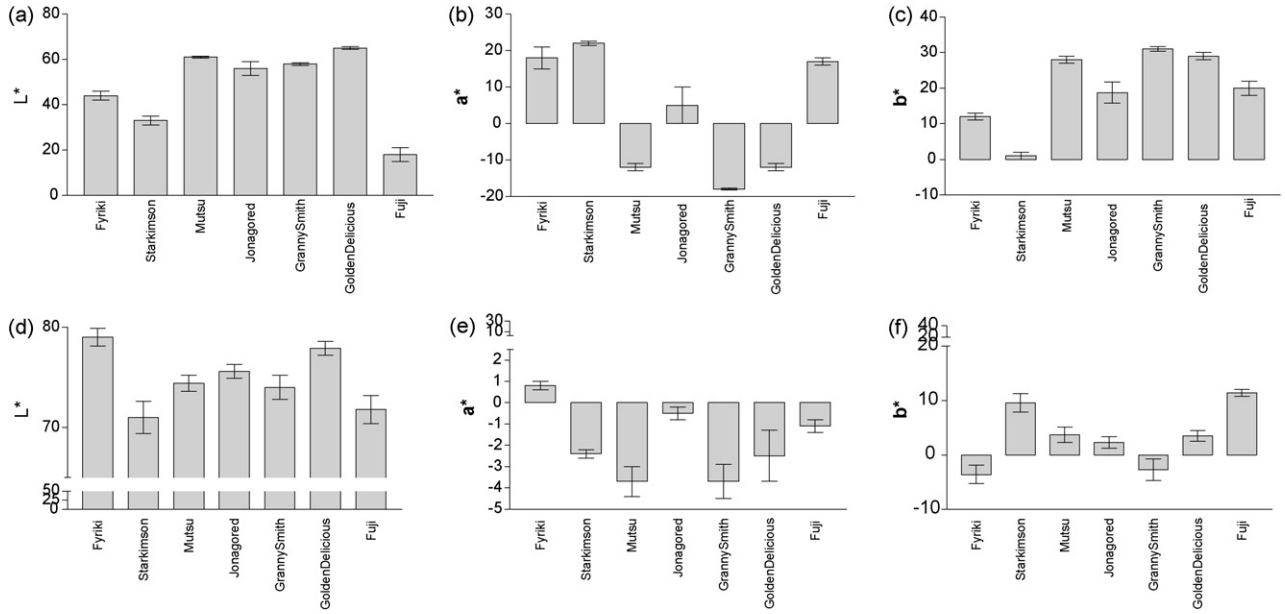

Fig. 2. Color L, a* and b* values in peel (a–c) and flesh (d–f) tissue from seven apple cultivars. Values represent mean ± S.E.

researchers (Wolfe et al., 2003; Tsao et al., 2003; Chinnici et al., 2004).

The studied apple cultivars had different coloration in peel and flesh (Fig. 2). The peel of Starkrimson was slightly more red (higher L and lower b* values) compared with Fyriki, and both cultivars were darker and more red colored compared with the green cultivars Granny Smith, Golden Delicious and Mutsu. In the bicolored cultivars Fuji and Jonagored, the skin color was either intermediate or similar to red or green cultivars. In flesh tissue, Fyriki was the brightest and reddest. Fuji (its parents are Red Delicious and Ralls Janet) had similar flesh color with Starkrimson and it was the most yellow. The green cultivars Golden Delicious, Granny Smith and Mutsu had similar flesh color being the most green and relatively dark colored. The peel color parameters were not correlated with the flesh color parameters (Table 1), suggesting that external color does not indicate for internal (flesh) color. Similar results were found for pomegranate (Drogoudi et al., 2005).

Jonagored contained the highest (19.6%) and Fyriki and Granny Smith contained the lowest (mean value 13.4%) soluble solids content (Fig. 3). Total acid content was highest in Granny Smith while the lowest value was found in Fyriki (Fig. 3).

Correlation analyses showed a negative linear correlation between the b* color value and the total antioxidant activity ($r = -0.860$) and phenolic content ($r = -0.826$) in peel (Table 1). PCA was applied to mean values of measured traits for detecting the most important factors of variability and to describe the relationship between variables and observations (Table 2). The most important variables integrated by the first component (46.9% of variance) were a* color, total phenolic and antioxidant activity in peel and total phenolics in flesh, while negative correlations had L and b in peel and total acids. The second component (33.2% of variance) was mainly correlated with L color and antioxidant activity in flesh while negative correlations had b* color and soluble solid content in flesh. Finally, the third component explained a relatively small percentage of variability (8.7%). The above results show that traits related either with peel or flesh, were mostly integrated in the first or second PCA components, respectively. It is suggested that a more nutritious peel may be darker, redder

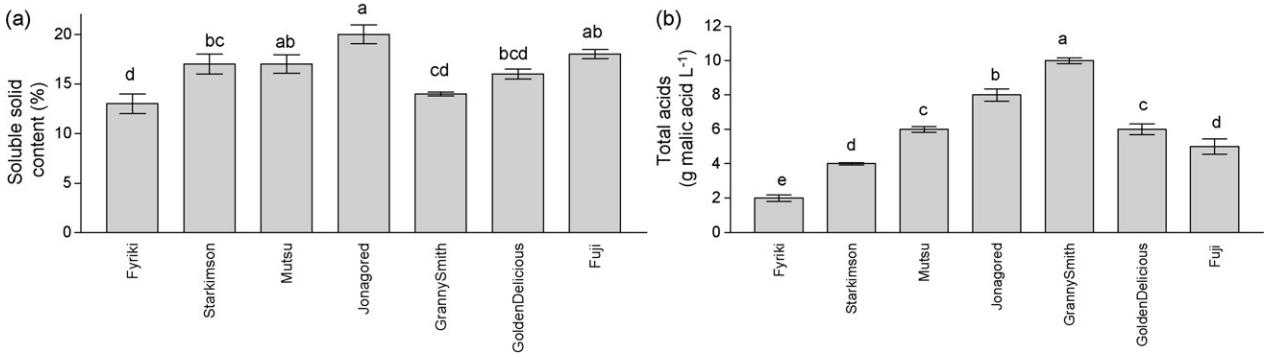

Fig. 3. (a) Total soluble solid (%), and (b) total acid content (g mallic acid L^{-1}) in flesh from seven apple cultivars. Values represent mean ± S.E. Different letters denote significant differences ($P < 0.05$); values bearing the same superscript are not significant different from one another.

Table 2
Apple characters with factor loadings and explained cumulated proportion of variation

Characters	Component 1 (46.9%)	Component 2 (33.2%)	Component 3 (8.7%)
Peel – L	**−0.905**	0.191	0.256
Peel – a*	**0.936**	−0.151	0.212
Peel – b*	**−0.949**	0.203	0.104
Flesh – L	−0.134	**0.862**	0.307
Flesh – a*	0.626	0.389	0.613
Flesh – b*	0.267	**−0.847**	0.199
Total soluble solids	−0.003	**−0.751**	0.553
Total acids	**−0.836**	−0.228	−0.191
Peel – total phenolics	**0.720**	−0.584	−0.001
Peel – antioxidant activity	**0.731**	−0.577	−0.258
Flesh – total phenolics	**0.762**	0.571	−0.005
Flesh – antioxidant activity	0.550	**0.718**	−0.297
Flesh – ascorbic acid	0.618	0.689	−0.001

Factor loadings $\geq |0.70|$ are marked in bold.

and bluer in color, while a more nutritious flesh may have a lighter color and lower soluble solid content.

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