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Comparison of physicochemical traits of red-fleshed, commercial and ancient apple cultivars

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Abstract

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Cultivation of apples is currently based on a limited number of commercial cultivars; as a consequence, ancient and local varieties have almost completely disappeared. Red-fleshed, ancient and commercial cultivars were analysed for flesh firmness, soluble solid content, pH, titratable acidity, total phenolics and anthocyanin contents, total antioxidant capacity, sugars and organic acids composition, to evaluate their nutraceutical value. The ancient cultivars, in particular cv. Magnana, were generally higher in organic acids, sugars content and total phenolics content in the flesh than the commercial cultivars considered. The red-fleshed cultivar was distinct from the ancient and commercial apples and resulted in an excellent source of antioxidants, with values of anthocyanins content and antioxidant capacity five times higher than the other cultivars; these values were comparable to those of berry species. In addition, the red-fleshed apple was rich in malic acid, citric acid, fructose and glucose. The breeding of red flesh apples is still in progress and should consider the use of ancient cultivars for their positive physicochemical characteristics to improve flavour and storage aptitude.

Keywords: *Malus domestica*; organic acids; sugars; antioxidant capacity; total phenolics content; anthocyanins

Apples are usually included in the daily diet thanks to their availability on the market during the whole year. Fruits provide nutrients and, at the same time, have a functional role in human health, with beneficial effects on one or more organism functions, preventing from cancer, cardiovascular diseases, asthma and pulmonary dysfunction and diabetes (Boyer et al. 2004). Due to their nutraceutical characteristics, apples fall within the class of food products defined 'functional foods' (Hyson 2011). In particular, phenolics, sugars and organic acids determine the quality of apples (Fuleki et al. 1994; Wu et al. 2007). Most of the phenolics in apples are concentrated in the skin and the greatest content is given by proanthocyanidins and anthocyanins (Łata et al. 2009). However, in several countries the common method of apple consumption requires the skin removal, with consequent minor antioxidant uptake.

Although the chemical-nutritional composition of fruit is common to all types of apples, there is an evident variability among fruits of different cultivars (Wu et al. 2007; Contessa et al. 2013). Several breeding programs, aimed at improving production and fruit quality, increased the offer of new cultivars with the partial renewal of the apple varietal panorama; yet, the pool of apple varieties available in the large-scale distribution is very small. The cultivation of ancient and local varieties, characterized by high nutraceutical value (Iaco-

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pini et al. 2010), has nowadays almost disappeared or is addressed to niche markets, in favour of commercial cultivars more productive and attractive to the consumer.

In this context, new apple varieties characterised by red flesh are being selected (Faramarzi et al. 2014). These apples contain elevated anthocyanin amount that determine the flesh and skin pigmentation, and are a healthy and attractive novelty for the consumer (Würdig et al. 2014).

This research is focused on analysis and comparison of the physiochemical characteristics between ancient, commercial and a red flesh cultivar. The knowledge on the chemical variability among different apple cultivars will be useful to improve nutritional quality and promote future breeding with an alternative approach than genetic modification (Espley et al. 2009).

MATERIAL AND METHODS

The study was carried out on apples of Brookfield® Gala, Galaxy Gala™, Golden Delicious, Redchief® as commercial cultivars, Grigia di Torriana, Magnana and Ronzé as ancient cultivars collected at maturity from fruit-growing farms in the traditional apple area of cultivation in Piedmont Region (North West Italy). The red-fleshed cultivar was sampled in an experimental orchard in Piedmont and originated from cross-pollination between a traditional red-fleshed Asian variety and the cv. Gala.

The characteristic of the apples are shown in Table 1. The ancient cultivars belong to the local Piedmont germplasm and are promoted for niche markets as “Ancient Piedmontese Apples”. At commercial ripeness four replicates of 10 apples per cultivar were picked to perform physical and chemical analysis.

The flesh firmness was measured using a fruit penetrometer with crossheads of 11 mm. The SSC was determined on the supernatant with a digital refractometer XS DBR 35 and expressed in °Brix. The pH and titratable acidity were determined using a pH meter and a semi-automatic titrator Titromatic 2S (Crison, Barcelona, Spain).

The extracts were obtained from the edible part of peeled fruits, following the common method of eating in Italy. The fruit extract was obtained as described by Contessa et al. (2013). The amount of total phenolics in fruit extracts was measured following the Folin-Ciocalteu procedure, according to the method of Slinkard and Singleton (1977). The total anthocyanin content was determined by a pH differential absorbance method (Cheng et al. 1991). Total antioxidant capacity was determined using the Ferric Reducing Antioxidant Power (FRAP) assay, according to the method of Benzie and Strain (1996) modified by Pellegrini et al. (2003).

The juice for the analysis was obtained as described in the determination of soluble solid content paragraph. The samples were centrifuged at 13,000 rpm for 15 min. 30 µl of internal standard (methyl-D-mannopyranoside, 0.2 mg/l C_2H_5OH 80%) were added to 50 µl of supernatant and completely evaporated in a concentrator centrifugal evaporator (5301 Eppendorf, Hamburg, Germany). Then 200 µl of C_2H_5OH were added to the sample and completely dried. The sample was dissolved in 500 µl of a pyridine solution containing methoxamine chloride 10 mg/ml and then placed in an oven at 62°C for 1 h for the oximation step. De-

Table 1. Maturity time in Piedmont Region, ground colour, over colour and flesh colour of commercial, ancient and red-fleshed cultivars

Cultivar	Maturity time	Ground colour	Overcolour	Flesh colour
Brookfield® Gala	Aug. 20–30	yellow-golden	red	creamy white
Galaxy Gala™	Aug. 20–30	yellow-golden	red	creamy white
Golden Delicious	Sept. 10–20	yellow-golden	–	cream
Redchief®	Sept. 10–20	yellow-green	red	creamy green
Grigia di Torriana	Oct. 10–20	green	–	creamy white
Magnana	Oct. 20–30	green	red	green-white
Ronzé	Nov. 1–10	yellow-green	red	creamy white pinkish
Red fleshed cv.	Sept. 10–20	yellow-green	red	rosy-red and white

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rivatization of sugars was performed using 200 μl of silylation solution (*N,O*-bis-(trimethylsilyl)trifluoroacetamide (BSTFA) containing 1% trimethylchlorosilane) added to each sample; vials were placed in an oven at 62°C for 1 hour. Aliquots of 1 μl of extract of the apple samples were analysed using a DANI 86.10 capillary gas chromatography (GC) (DANI Instruments S.p.A., Cologno Monzese, Italy). A MEGA-1 fused silica capillary column (25 m × 0.32 mm ID × 0.25 μm film thicknesses) was used with helium as carrier gas at a constant flow rate of 1.9 ml/min. The injector was a programmed temperature vaporising (PTV) set at the temperature of 100°C, then programmed to 330°C at 800°C/min and held 15 minutes. The column temperature program consisted of a first step at 130°C for 2 min, temperature increase at 4°C/min to 190°C, followed by a temperature increase at 8°C/min to 320°C maintained for 1 minute. Detector temperature was set at 330°C. Sugar and acid identification and quantification was performed by the software DDS1032 for Windows (DANI Instruments S.p.A., Cologno Monzese, Italy).

Data were analysed by ANOVA; means comparison and significant differences were calculated using the Tukey's test. Statistical analysis was carried out using the SPSS 21.0 software Inc. (Chicago, USA).

RESULTS AND DISCUSSION

Data on the physiochemical analysis of commercial, ancient and a red flesh apple cultivars are reported in Table 2. Flesh firmness, SSC and acidity are considered the main criteria used to determine the fruit maturity. While SSC largely determines the taste of apples, flesh firmness is used to estimate fruit maturity, select proper harvest time for apple cultivars and how the harvested fruit should be handled and marketed. In this study, the fruit texture showed statistical differences among cultivars confirming that apple fruit firmness tends to be greatly influenced by genetic factors, as observed by BAI et al. (2005), and by maturity time. The ancient cultivars, characterized by late maturity (September–November) showed the highest resistance to penetration, followed by the red-fleshed and commercial cultivars, with value ranging from 9.91 kg/cm^2 for cv. Magnana to 6.40 kg/cm^2 for cv. Redchief®. Soluble solids content is a good indicator of sweetness and sugar content of apples. SSC varied between 14.44°Brix, for the red-fleshed cultivar, and 11.57°Brix (cv. Galaxy Gala^{TM}). High values of soluble solids content were reached also in cvs Grigia di Torriana (14.40°Brix), Golden Delicious (13.88°Brix), Ronzé (13.34°Brix) and Magnana (13.08°Brix). The red-fleshed cvs Ronzé and Magnana were the most acidic varieties, while the highest pH values were found in cvs Grigia di Torriana and Redchief® (4.10 and 3.95, respectively). Intermediate pH values were observed in cvs Golden Delicious, Brookfield® Gala and Galaxy Gala^{TM}. Titratable acidity is the best indicator of the sensory attribute acid taste and is used as a predictor of commercial and organoleptic ripeness. This parameter is important for the assessment of fruit quality and contributes to give the characteristic apple flavour (Harker et al. 2003). The highest titratable acidity was found in cv. Golden Delicious (65.68 meq/l), followed by Brookfield® Gala (60.89 meq/l), Galaxy Gala^{TM} (56.87 meq/l) and Magnana (54.74 meq/l). No statistical differences were found between red-fleshed cultivar (46.03 meq/l) and Redchief® (37.64 meq/l). Cv. Grigia di Torriana showed the lowest titratable acidity (25.06 meq/l).

Consumers often have distinct preferences for acid or sweet tasting apples (Nour et al. 2010). °Brix and °Brix/titratable acidity explain the consumer perception of apples sweetness. In some studies, this relationship has probably been concealed by the influence of fruit maturity and starch degradation on fruit taste (Yuen et al. 1995), while other authors showed a good relationship between °Brix or °Brix/titratable acidity and consumers acceptability at ripeness (Skendrović Babojelić et al. 2007). The °Brix/acid ratio is usually a better predictor of an acid's flavour impact than °Brix or acid alone. The commercial cvs Golden Delicious, Brookfield® Gala, Galaxy Gala^{TM} and Magnana reached a balanced °Brix/acid ratio (3.16, 3.12, 3.04 and 3.58, respectively), while cv. Ronzé, the red-fleshed cv. and Redchief® confirmed their sweet tasting with °Brix/acid ratio values of 3.90, 4.71 and 4.96, respectively. The °Brix/acid ratio of cv. Grigia di Torriana apples confers a characteristic sweet flavour to this variety.

The total phenolic and anthocyanin contents and the total antioxidant capacity of the fruit flesh of the red-fleshed, commercial and ancient cultivars were evaluated and the results are reported in Table 2. Cvs Grigia di Torriana and Magnana, two of the ancient varieties analysed, were the ones

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Table 2. Flesh firmness (kg/cm^2), soluble solids content (SSC; °Brix), pH, titratable acidity (TA; meq/L), °Brix/acid ratio, total phenolic content (TPC; mg GAE/100 g f.w.), total anthocyanin content (TAnC; mg C3G/100 g f.w.) and total antioxidant capacity (FRAP; mmol Fe^{2+}/kg f.w.) in commercial, ancient and red fleshed cultivars

Cultivar	Flesh firmness	SSC	pH	TA	°Brix/acid ratio	TPC	TanC	FRAP
Brookfield® Gala	8.12^{bc}	12.47^{cd}	3.68^{bc}	60.89^{ab}	3.12^{c}	44.06^{de}	< 0.01^{b}	9.85^{b}
Galaxy Gala™	6.93^{de}	11.57^{d}	3.70^{b}	56.87^{abc}	3.04^{c}	47.33^{cde}	0.22^{b}	9.02^{b}
Golden Delicious	6.68^{e}	13.88^{ab}	3.50^{c}	65.68^{a}	3.16^{c}	49.52^{cd}	< 0.01^{b}	8.10^{b}
Redchief®	6.40^{e}	12.48^{cd}	3.95^{a}	37.64^{d}	4.96^{b}	61.44^{bc}	< 0.01^{b}	12.21^{b}
Grigia di Torriana	8.02^{bc}	14.40^{a}	4.10^{a}	25.06^{e}	8.66^{a}	90.12^{a}	< 0.01^{b}	9.47^{b}
Magnana	9.91^{a}	13.08^{bc}	3.22^{d}	54.74^{abc}	3.58^{c}	74.58^{ab}	< 0.01^{b}	13.10^{b}
Ronzé	8.81^{b}	13.34^{abc}	3.19^{d}	51.39^{bc}	3.90^{b}	31.42^{e}	< 0.01^{b}	9.68^{b}
Red fleshed cv.	7.8^{cd}	14.44^{a}	3.08^{d}	46.03^{cd}	4.71^{b}	70.81^{b}	8.22^{a}	58.02^{a}

means followed by the same letter in a column are not significantly different at $P = 0.05$ (Tukey's test); f.w. – fresh weight

with the highest total phenolic content (90.12 and 74.58 mg galic acid equivalent (GAE)/100 g of fresh weight, respectively), while cvs Ronzé, Brookfield® Gala, Galaxy Gala^{TM} and Golden Delicious had the lowest values (31.42, 44.06, 47.33 and 49.52 mg GAE/100 g of fresh weight, respectively). The commercial cv. Redchief® and the red-fleshed cultivar had intermediated values (61.44 and 70.81 mg GAE/100 g f.w., respectively).

Apples are consistently described as a good source of health-relevant phenolics (Francini et al. 2013) and these results prove that the genetic variability within apple germplasm can provide a significant genetic variation in the amount and composition of phenolics.

Specific studies aimed at comparing total phenolic content in commercial and ancient apple cultivars were performed by Iacopini et al. (2010) and Ceymann et al (2012). The commercial cultivars were characterized by lower phenolic content and antioxidant activity compared to old varieties, in agreement with our results. A direct correlation exists between the levels of anthocyanins and the fruit skin and flesh colour (Contessa et al. 2013). A significantly higher anthocyanin content was recorded in the red-fleshed cultivar (8.22 mg C3G/100 g f.w.), while the mean of total anthocyanin content in the light coloured-flesh cultivars was less than 0.01 mg C3G/100 g f.w. (Table 2), confirming that red colour is anthocyanin accumulation. Flesh colour is controlled by a gene called MYB10 that is expressed at higher rate in the red-fleshed apples than in the white fleshed varieties (Espley et al. 2007). Malec et al. (2014) reported that the major constituents present in red-fleshed apple juice were flavanols with over 70% content of procyanidins in apples, followed by anthocyanins, with 9% of average total polyphenol content. Similar results were observed in this study on the red-fleshed cultivar.

Although the red-fleshed cultivar showed good chemical and physical characteristics at harvest, after 6 months of storage the samples showed the most common unwanted characteristics of the red flesh varieties: poor taste, low texture and internal browning as observed also by Francini and Sebastiani (2013). Espley et al. (2013) observed that internal browning is present in fruit of transgenic cv. Royal Gala lines modified with the MYB10 transcription factor under a constitutive promoter after 12 weeks of storage at 0.5°C, suggesting a potential postharvest issue for fruit with high anthocyanin content.

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Table 3. Acids and sugars composition (mg/100 g) of commercial, ancient and red-fleshed cultivars

Cultivar	Malic acid	Succinic acid	Citric acid	Quinic acid	Mannitol	Sorbitol	*Myo*-inositol	Sucrose	Raffinose	Fructose	Glucose	Xylose	Total organic acids	Total sugar alcohols	Total sugars
Brookfield® Gala	445.34^{c}	18.53^{abc}	4.60^{de}	16.44^{cd}	1.52^{d}	239.61^{b}	20.93^{c}	3,218.40^{c}	16.21^{ab}	6,328.20^{c}	1,584.97^{d}	69.51^{cd}	11,481.86^{de}	262.06^{b}	11,217.30^{de}
Galaxy Gala™	409.88^{c}	19.74^{ab}	4.34^{de}	15.42^{d}	9.09^{bc}	256.97^{b}	15.77^{d}	1,977.45^{d}	7.18^{c}	6,425.65^{c}	1,693.26^{d}	83.62^{bc}	10,471.50^{e}	281.84^{b}	10,187.16^{e}
Golden Delicious	456.14^{c}	10.39^{cde}	6.63^{cd}	8.80^{e}	7.90^{c}	329.93^{b}	40.73^{a}	1,532.64^{de}	12.765^{abc}	7,807.91^{ab}	2,596.44^{b}	73.18^{c}	12,404.00^{cd}	378.57^{b}	12,022.94^{cd}
Redchief®	233.64^{d}	15.44^{bcd}	2.51^{e}	53.49^{a}	7.33^{c}	344.84^{b}	7.02^{e}	1,130.90^{e}	12.86^{abc}	7,655.13^{ab}	2,948.48^{b}	113.81^{a}	12,222.88^{cd}	359.19^{b}	11,861.19^{cd}
Grigia di Torriana	215.04^{d}	8.42^{cd}	8.79^{c}	33.65^{b}	26.36^{a}	381.72^{b}	10.62^{e}	3,400.26^{bc}	18.43^{a}	7,026.57^{bc}	3,553.11^{a}	80.31^{bc}	14,499.89^{ab}	418.70^{b}	14,078.68^{ab}
Magnana	681.12^{a}	24.17^{a}	19.26^{a}	9.16^{e}	14.20^{b}	845.04^{a}	24.62^{c}	6,128.11^{a}	11.50^{bc}	5,002.50^{d}	1,429.10^{d}	100.78^{ab}	13,558.36^{abc}	883.86^{a}	12,672.00^{bc}
Ronzé	551.86^{b}	6.84^{e}	8.64^{c}	21.59^{c}	10.36^{bc}	371.49^{b}	24.21^{c}	4,111.92^{b}	13.51^{abc}	6,440.15^{c}	2,188.97^{c}	48.35^{d}	13,211.45^{bc}	406.06^{b}	12,802.89^{bc}
Red fleshed cv	748.47^{a}	15.63$^{a–d}$	13.92^{b}	9.09^{e}	5.92^{cd}	218.96^{b}	34.77^{b}	2,230.26^{d}	9.93^{bc}	8,102.56^{a}	3,431.71^{a}	77.97^{bc}	14,864.59^{a}	259.65^{b}	14,602.44^{a}

means followed by the same letter in a column are not significantly different at $P = 0.05$ (Tukey's test)

The values of total antioxidant capacity, expressed as FRAP, showed significant differences among the red-fleshed, commercial and ancient cultivars. In particular, the red flesh apple reached a TAnC of 58.02 mmol Fe^{2+}/kg f.w., five times greater than the mean value of commercial and ancient cultivars. No statistical differences were found among commercial and ancient cultivars, although the ancient apples reached an antioxidant capacity mean value higher in respect to commercial varieties (10.75 mmol Fe^{2+}/kg f.w. and 9.80 mmol Fe^{2+}/kg f.w., respectively).

In a study carried out in Oregon on the effect of apple consumption on human health, Lotito et al. (2004) observed an increase by 12% of FRAP value in plasma blood samples of 6 healthy patients after eating 5 commercial apples. The total antioxidant capacity of the red flesh cultivar reached a value comparable with the value described in black currant (Contessa et al. 2013), confirming that red flesh apples could be an excellent source of bioactive compounds. This suggests that the consumption of red flesh apples, with higher antioxidant capacity in respect to commercial apple cultivars, could lead to a higher amount of antioxidant compounds available for the human body.

Apple flesh juice extracts were analysed by gas chromatography (GC). Data presented in Table 3 illustrate the acids and sugars composition variability among red flesh, commercial and ancient apple cultivars. The GC pattern of acids and sugars composition is similar in all the examined cultivars and in accordance with literature (Wu et al. 2007; Fuleki et al. 1994).

The amount of individual acid and sugar compounds was expressed by taking into account the mean fresh weight for each of the apple cultivars. The predominant organic acid is malate (average 467.69 mg/100 g), as indicated by other researchers (Karadeniz, Ekşi 2002; Wu et al. 2007), followed by quinic acid (average 20.96 mg/100 g), succinic acid (average 14.90 mg/100 g) and citric acid (average 8.59 mg/100 g). The concentration of each compound showed a high variability among cultivars. The red-fleshed apple and cv. Magnana reached the highest malate concentration (748.47 mg/100 g and 681.12 mg/100 g, respectively), followed by cv. Ronzé (551.86 mg/100 g), and the values were correlated with titratable acidity, as reported by Markowski et al. (2009). No statistical differences were observed between Brookfield® Gala, Galaxy Gala™ and Golden Delicious varieties, while

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cv. Redchief® showed a lower malic acid concentration in respect to the other commercial cultivars.

Succinate acid ranged from 24.17 mg/100 g for cv. Magnana to 6.84 mg/100 g for cv. Ronzé; no statistical differences were found between cvs Magnana, Galaxy Gala™, Brookfield® Gala and the red flesh apple. Citric acid was present in a concentration similar to that reported in other studies and it is markedly higher in cv. Magnana (19.26 mg/100 g), followed by red-fleshed cultivar (13.92 mg/100 g). The commercial varieties showed the lowest citrate concentration. The apple cultivars with the highest quinic acid concentration were cvs Redchief® and Grigia di Torriana; Ronzé, Brookfield® Gala and Galaxy Gala™ showed half of the concentration. In agreement with Wu et al. (2007), who compared commercial and traditional apple cultivars, the lowest concentration of quinic acid was found in cv. Golden Delicious.

In general, cv. Magnana and the red-fleshed cultivar presented a similar acidic profile and, together with cvs Grigia di Torriana and Ronzé, resulted in the highest amount of organic acids, in particular malate, succinate and citrate. The regular consumption of fruit acids is helpful in preventing illness and slight metabolic disorders in the human body, with action of protection for the gastric mucosa, stimulating digestion and favouring diuresis. In particular, malic acid dissolves uric acid, and is therefore an important source of relief when someone suffers from gout or rheumatism (Hecke et al. 2006).

The amount of sugars in the cultivars is shown in Table 3. There were numerous studies examining apple sugar profiles (Fuleki et al. 1994; Karadeniz, Ekşi 2002; Wu et al. 2007). In agreement with these authors, fructose, sucrose and glucose were identified as the principal sugars. Significant differences in sugar content were found among apple juices processed from the different varieties. In particular, the red-fleshed cultivar and the ancient cultivars showed the highest sugar content, while for total sugar alcohols statistical differences were found only between cv. Magnana and the other cultivars. Cvs Grigia di Torriana, Magnana and Ronzé showed the highest mannitol, sorbitol and sucrose concentration. Regarding sorbitol content no statistical differences were observed among cultivars, except for cv. Magnana with a value more than twice higher than the other apple varieties. Sorbitol is used as standard sweetener in diabetic diets and as moistening conditioning agent in certain foods and pharmaceutical products. The sorbitol intake showed an effect on controlling dental caries and it is used as an ingredient in several sugar-free chewing gums (Burt 2006).

Cv. Golden Delicious and the red-fleshed cv. resulted as excellent sources of *myo*-inositol (40.73 and 34.77 mg/100 g, respectively). Regular consumption of foods rich in *myo*-inositol (fruits, meats, milk, vegetables, beans, whole grains, nuts and yeasts) (Clements, Darnell 1980) offers beneficial health effects (Spallholz et al. 1999). *Myo*-inositol is used in treatments for depression, panic disorder, diabetic neuropathy, respiratory distress syndrome, obsessive-compulsive disorder, polycystic ovary syndrome, insomnia, excess cholesterol, psoriasis and Alzheimer's disease (Gerhauser 2008; Ker et al. 2010).

The red-fleshed cv., and cvs Golden Delicious and Redchief® contained the highest amount of fructose, while the glucose content was highest in cv. Grigia di Torriana and in the red-fleshed apple. Raffinose was present in small amount in all varieties and showed the highest contents in cvs Grigia di Torriana and Brookfield® Gala. The red-fleshed cv. reached interesting values of fructose and glucose, but low concentration in sucrose and sorbitol. In agreement with Espley et al. (2013), the red-fleshed cultivar showed a higher sugar content compared to the commercial varieties; moreover the major sugar was fructose, the sweetest sugar and the main responsible compound for the sweet taste in apple. However, the sucrose concentration in the red-fleshed cultivar was approximately 50% lower than in ancient cultivars. Xylose concentration was low in all cultivars, the highest amounts were observed in cvs Redchief® and Magnana; the other cultivars showed values ranging from 83.62 mg/100 g for Galaxy Gala® to 48.35 mg/100 g for Ronzé.

CONCLUSION

In the eight apple varieties analysed, the ancient cultivars were distinct from the commercial ones for the physiochemical characteristics, with interesting organic acids and sugars composition and total phenolics content in the flesh, while the commercial cultivars showed a good °Brix/acid ratio. The red-fleshed cultivar was distinct from the others for the high TAnC and for the antioxidant capacity, with value comparable to berry species. In

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addition, the red-fleshed cultivar was rich in malic acid, *myo*-inositol, fructose and glucose; it showed interesting and healthy traits being an excellent source of antioxidants. The major limit of the red-fleshed varieties could be the post-harvest storage.

The characteristics of ancient and red-fleshed cultivars should be considered together for the choice of parents in breeding programs aimed at selecting varieties with improved antioxidant capacity, nutraceutical properties, tasting quality and post-harvest storage aptitude.

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