JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

ARTICLE

pubs.acs.org/JAFC

Influence of Cultivar, Harvest Time, Storage Conditions, and Peeling on the Antioxidant Capacity and Phenolic and Ascorbic Acid Contents of Apples and Pears

Claire Kevers,[*,†,‡] Joël Pincemail,[§] Jessica Tabart,[†,‡] Jean-Olivier Defraigne,[§] and Jacques Dommes[†]

[†]Plant Molecular Biology and Biotechnology Unit, B22, [‡]CEDEVIT (ASBL), Plant Biology Institute, B22, and [§]CREDEC, Pathology Tower, B23, University of Liège, Sart Tilman, B-4000 LIEGE Belgium

ABSTRACT: Apple and pear fruits are important sources of secondary plant metabolites and one of the major sources of dietary phenolics consumed all year round. The aim of this work was to identify the main variables influencing phenolic content and antioxidant capacity in apples. Higher phenolic and antioxidant contents were observed in some varieties (such as the Delbar Estival apple and Durondeau pear). Storage conditions were important. Our results also showed that fruits should be consumed rapidly after purchase and with their peel. After one week of domestic storage, the ascorbic acid content was found to decrease by 75%. Peeling led to a more than 25% decrease in total phenolics and ascorbic acid. The harvest time (at normal ripeness) had only a limited impact, but significant year-to-year variations were observed. In conclusion, well-chosen and well-stored apples and pears may contribute to an antioxidant-rich diet if consumed rapidly and with their peel.

KEYWORDS: Antioxidant, cultivar, peeling, phenolics, storage

1. INTRODUCTION

There is considerable evidence showing that a greater intake of fruits and vegetables contributes to improved health and well-being by reducing the risk of diseases such as cardiovascular disease and some forms of cancer.[1,2] On the basis of this evidence, the World Health Organization has recommended consuming at least 5 servings of fruits and vegetables per day. Positive health effects have been attributed to the high antioxidant content of plant tissues.[3] Fruits and vegetables contain many different antioxidant compounds (e.g., polyphenolics, vitamin C, carotenoids, and vitamin E). Phenolic compounds are potent antioxidants representing a substantial portion of all dietary antioxidants.[4]

Apples are quantitatively the most consumed fruits in several countries in Europe and America. Most of the production is consumed fresh, while a lesser part is processed into juices, concentrates, and purees. Apples are a major source of phenolic compounds because their consumption is widespread, and they are available in the market throughout the year. Generally, five major polyphenolic groups are found in various apple varieties: hydroxycinnamic acids, flavan-3-ols/procyanidins, anthocyanins, flavonols, and dihydrochalcones.[5]

Pears rank relatively low among fruits as regards to their antioxidant activity and phenolic content, but they have a higher antioxidant activity than many common vegetables.[6] Despite their moderate antioxidant activity, the contribution of pears to the intake of antioxidants can be substantial in European countries, where the annual per capita consumption is high (it can reach about 14 kg) (FAO 2007). Among the classes of plant phenolics, four are also reported to be present in pear fruits: phenolic acids, flavonols, flavan-3-ols, and anthocyanins.[7]

In a fruit, the range and abundance of phenolic compounds can vary according to the growth period,[8] the year of harvest,[9] the geographic location,[10] the storage conditions,[11] and most importantly, genetic variation.[5]

Food producers are showing more and more interest in developing products with an increased level of certain health-protecting compounds, such as strong antioxidants, to address the growing interest of consumers in the relationship between diet and health. The aim of this article was to identify the main parameters liable to influence the antioxidant activity of consumed apples and pears. Fourteen apple cultivars and 6 pear cultivars were compared as regards to their total phenolic and ascorbic acid contents and antioxidant capacity. To assess potential year-to-year differences, apples and pears from two different harvest years were analyzed. The effect of harvest time (successive harvests at the ideal degree of ripeness for commercial use) was also measured. In the case of apples, the effects of domestic storage and long-term industrial storage were also investigated, as was the effect of peeling.

2. MATERIALS AND METHODS

2.1. Fruit Material. Fourteen varieties of apples (Belgica, Boskoop, Braeburn Hitweel, Braeburn Mariri Red, Delbard Estival, Elstar, Gala, Golden, Greenstar, Jonagold Red, King Jonagold, Pinova, Santana, and Topaz) and six varieties of pears (Beurre Alexander Lucas, Conference, Doyenne de Comice, Durondeau, Sweet Sensation, and Triomphe de Vienne) were obtained from the Belgian fruit auction of St. Truiden (Belgische Fruitveiling of St. Truiden), associated with the test center of Hillwel and Merdorp. The materials were collected on the day of harvest (dates indicated in Tables 1 and 2), stored at 4 °C, and used the next day for analysis. Pips were removed from all fruits before analysis. The fruits were always harvested during the period of maximum production yield. For some experiments, two (Conference pears) or

Received: March 13, 2011
Accepted: May 6, 2011
Revised: May 5, 2011
Published: May 06, 2011

Table 1. Antioxidant Capacity (μmol TE/100 g FW) and Ascorbic Acid (mg AA/100 g FW), and Total Phenolic (mg CAE/100 g FW) Contents of Apples from Various Cultivars Harvested in 2009[a]

harvest date	cultivar	phenolics (mgCAE/100 g FW)	ascorbic acid (mgAA/100 g FW)	ORAC (μmolTE/100 g FW)
08−24	Delbard Estival	313 ± 13 c	35.3 ± 1.3 a	4917 ± 249 a
09−14	Gala	225 ± 10 d	20.9 ± 0.3 c	3275 ± 249 b
09−07	Belgica	236 ± 11 d	16.6 ± 2.2 d	2726 ± 243 b,c
09−28	Golden	365 ± 28 b	32.8 ± 2.4 a	2647 ± 229 c
10−19	Braeburn Hilwell	208 ± 8d,e	11.6 ± 0.4 e	2505 ± 246 c
09−14	Elstar	140 ± 10 f	21.6 ± 0.3 c	2463 ± 196 c
09−28	Boskoop	447 ± 24 a	31.4 ± 2.5 a	2441 ± 236 c
10−05	Jonagold Red	298 ± 22 c	12.3 ± 0.6 e	2346 ± 156 c
10−19	Braeburn Mariri Red	278 ± 22 c	22.9 ± 0.5 c	2342 ± 187 c
10−05	GreenStar	193 ± 12 e	15.6 ± 0.9 d	1856 ± 147 d
09−28	Topaz	202 ± 14 d,e	27.3 ± 1.1 b	1352 ± 118 e
09−28	Pinova	240 ± 15 c,d	34.4 ± 1.4 a	1218 ± 88 e
09−28	King Jonagold	274 ± 19 c	31.1 ± 2.3 a	1130 ± 109 e
09−28	Santana	166 ± 13 f	19.3 ± 1.1 c,d	1101 ± 105 e

[a] Significant differences as determined by ANOVA ($p < 0.05$) are indicated by different letters.

Table 2. Antioxidant Capacity (μmol TE/100 g FW) and Ascorbic Acid (mg AA/100 g FW) and Total Phenolic (mg CAE/100 g FW) Contents of Pears from Various Cultivars Harvested in 2009[a]

harvest date	cultivar	phenolics (mgCAE/100 g FW)	ascorbic acid (mgAA/100 g FW)	ORAC (μmolTE/100 g FW)
09−14	Durondeau	304 ± 14 a	8.0 ± 0.6 c	4251 ± 221 a
09−14	Conference	158 ± 11 c,d	21.6 ± 0.4 b	2749 ± 204 b
08−24	Triomphe de Vienne	142 ± 9 d	7.5 ± 0.5 c	2423 ± 276 b
09−14	Doyenne du Comice	109 ± 10 e	19.8 ± 0.4 b	2278 ± 145 b,c
09−28	Sweet Sensation	260 ± 16 b	29.7 ± 1.0 a	1925 ± 178 c
09−28	Beurre Alexander Lucas	173 ± 17 c	25.9 ± 2.5 a	1468 ± 121 d

[a] Significant differences as determined by ANOVA ($p < 0.05$) are indicated by different letters.

three (King Jonagold apples) successive harvests were carried out during the production period, at approximately 2-week intervals.

For the study on long-term storage, apples (King Jonagold) were stored in three different cold rooms: at 1 °C (1.5% O_2; 2.0% CO_2), at 1 °C under ultra low oxygen (ULO, 0.9% O_2; 1.2% CO_2), and under the latter conditions after pretreatment with 1-methylcyclopropene (1-MCP). The apples were analyzed directly after long-term storage and after 7 additional days at 20 °C in a normal atmosphere (to simulate domestic storage).

The effect of peeling was measured on apples stored for a few months at 1 °C.

2.2. Sample Preparation. In each experiment, 6 samples of 4 g of fresh material were used. Each 4-g sample consisted of slices collected from 5 different fruits and from the differently colored parts of the fruit if necessary. Three of the samples were independently ground in a blender with 80 mL of extraction solvent: acetone (70%), water (28%), and acetic acid (2%).[12] The mixture was shaken for 1 h at 4 °C and centrifuged at 17 000*g* for 15 min. The supernatant was used for the antioxidant capacity assays and total phenolics measurements.[13] For determination of the ascorbic acid content, the three other samples were independently ground with 1 g of quartz and 80 mL of extraction solution (20 g/L metaphosphoric acid). The mixture was shaken for 1 h at 4 °C and centrifuged at 15 000*g* for 15 min. The supernatant was used for the assays. For each experiment, the analyses performed on each extract were done in duplicate on the same day, except for the ORAC assay.

2.3. Total Phenolics. Total phenolics were determined by the Folin−Ciocalteu method. An appropriately diluted extract (3.6 mL) was mixed with 0.2 mL of Folin−Ciocalteu reagent, and 3 min later, 0.8 mL of sodium carbonate (20% w/v) was added. The mixture was heated at 100 °C for 1 min. After cooling, the absorbance at 750 nm was measured. Chlorogenic acid (Sigma) was used as the standard, and results were expressed in mg of chlorogenic acid equivalents (CAE) per 100 g fresh weight (FW). Analyses were performed in duplicate on each sample.

2.4. Hydrophilic Antioxidant Capacity. ORAC assays were carried out on a Victor 3 (PerkinElmer) plate reader. The temperature of the incubator was set at 37 °C. Procedures were based on the method of Wu et al.[14] Briefly, 2,2′-azobis-2-methyl-propanimidamide dihydrochloride (AAPH) was used as the peroxyl radical generator, trolox as the standard, and fluorescein as the fluorescent probe. Fluorescence filters were used for an excitation wavelength of 485 nm and an emission wavelength of 520 nm. Twenty-five microliters of diluted sample, blank, or trolox calibration solution was mixed with 150 μL of 4 μM fluorescein and incubated for 15 min at 37 °C before the injection of 25 μL of AAPH solution (173 mM). The fluorescence was measured every 2 min for 4 h. All samples were analyzed in duplicate at three different dilutions. The final ORAC values were calculated from the net area under the decay curves and were expressed in μM trolox equivalents (TE) per 100 g FW.

2.5. Ascorbic Acid. The 2,6-dichloroindophenol (DCIP) method of the Association of Vitamin Chemists[15] was used to measure only reduced ascorbic acid. A standard curve was prepared with the help of a series of solutions with known ascorbic acid concentrations. Samples diluted in 5% metaphosphoric acid or ascorbic acid calibration solution (600 μL) were mixed with 500 μL of 10% metaphosphoric acid, 300 μL of citrate buffer (pH 4.15), and 300 μL of DCIP (0.1 mg/mL). Optical density blanching was used. For each sample, the blank value was determined after the addition of 60 μL of ascorbic acid (1 mg/mL) so as

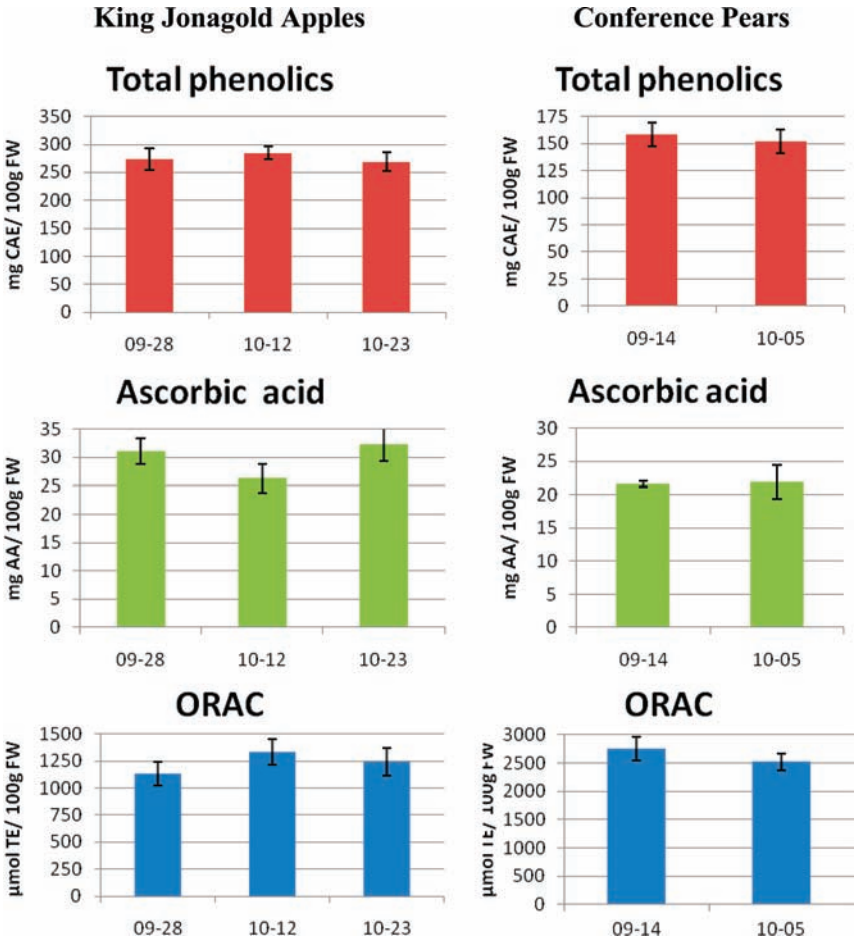

Figure 1. Antioxidant capacity (μmol TE/100 g FW), ascorbic acid content (mg AA/100 g FW), and total phenolics (mg CAE/100 g FW) in ripe apples (King Jonagold) and pears (Conference) harvested at various dates in 2009, as indicated on the figure. No significant difference was observed.

to measure the interference due to sample color. The results were expressed in mg of AA per 100 g FW.

2.6. Statistical analyses. All results presented are the means (±SE) of three independent extractions. The data were subjected to analysis of variance (ANOVA-1) to evaluate the significance of differences between various conditions ($P < 0.05$).

3. RESULTS AND DISCUSSION

The apple and pear varieties chosen for this survey are representative of those found on the market in Belgium.

Although various methods have been developed in recent years for simple evaluation of the total antioxidant capacity of biological samples and food, this effort has failed to yield a method of choice that can really accurately measure the total antioxidant capacity of samples. To evaluate the antioxidant capacities of foods, three methods have emerged as the most popular ones: determining the oxygen radical absorbance capacity (ORAC, where the measurement of fluorescence increases sensitivity and permits a much lower molar ratio of antioxidant sample), determining the total phenolic content (bioactive antioxidant compounds), and measuring 2,2-diphenyl-1-picryhydrazyl (DPPH) radical scavenging (which is quick and simple). These last two methods are based on redox reactions, and there is generally a good linear correlation between their results, suggesting that phenolic compounds largely account for the antioxidant capacity measured with DPPH. Here, we have chosen to focus on the ORAC assay and total phenolic content evaluation.

3.1. Antioxidant Capacity and Phenolic and Ascorbic Acid Contents of Various Apple Cultivars. The average total phenolic content of apples was 256 mg/100 g fresh fruit, with significant differences according to the apple variety (Table 1). Boskoop and Golden showed much higher total phenolic contents than any other variety in this study. The phenolic content was found to vary from 140 to 447 mg/100 g FW according to the variety, in the following increasing order: Elstar, Santana, Green Star, Topaz, Braeburn Hilwell, Gala, Belgica, Pivona, King Jonagold, Braeburn Mariri Red, Jonagold Red, Delbard Estival, Golden, and Boskoop. In other varieties, Vrhovsek et al.[16] found a mean total phenolic content in a similar range, between 66 and 212 mg/100 g. Such differences can be attributed to the genetic origin and thus to different levels of the different classes of phenolic compounds. These data confirm that regular dietary consumption of apples can contribute a considerable amount of phenolics. A single serving of apple (150 g) can provide 210 mg (Elstar) to more than 650 mg (Boskoop) of total phenolics. Such variations have been observed for other varieties in Italy,[16] Poland,[5] and New Zealand.[10]

Analysis of ascorbic acid (AA) in the various apple cultivars revealed high values (above 30 mgAA/100 g FW) for the varieties Delbard Estival, Pinova, Golden, Boskoop, and King Jonagold. The ascorbic content of the other cultivars was 2 to 3 times lower.

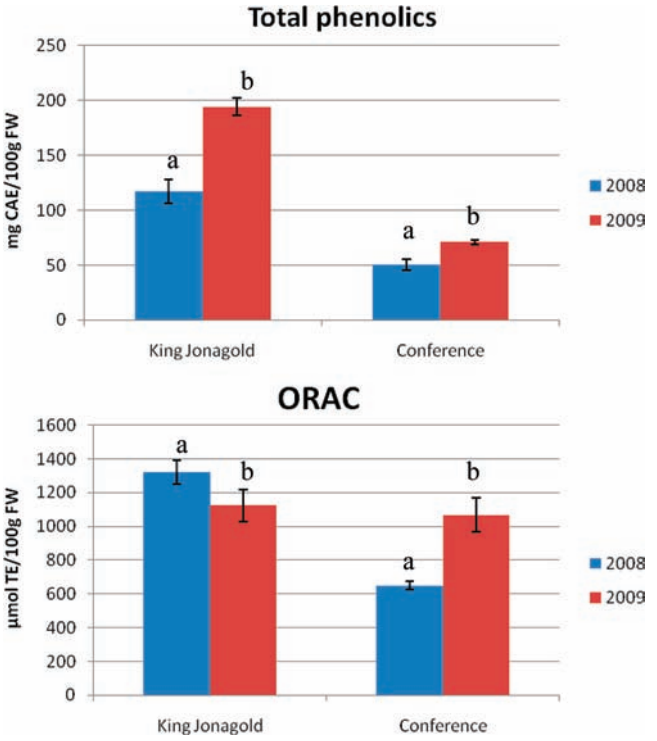

Figure 2. Antioxidant capacity (μmol TE/100 g FW) and total phenolics (mg CAE/100 g FW) in apples (King Jonagold) and pears (Conference) harvested on the same day (October 12) in 2008 and 2009. Significant differences as determined by ANOVA ($p < 0.05$) are indicated by different letters.

Such major between-variety differences in ascorbic acid content have also been observed by Vrhovsek et al.[16] Such variations in phenolic compounds and ascorbic acid should be at least partially responsible for variations in the antioxidant capacity of these fruits. Different genotypes showed major differences in antioxidant capacity (ORAC assay) (Table 1). On a fresh weight (FW) basis, Delbard Estival showed the highest antioxidant capacity (4917 ± 249 μmol TE/100 g), followed by Gala (3275 ± 249 μmol TE/100 g) and Belgica (2726 ± 243 μmol TE/100 g). King Jonagold (1130 ± 109 μmol TE/100 g) and Santana (1101 ± 105 μmol TE/100 g) showed the lowest antioxidant capacities, more than 4 times lower than that of Delbard Estival. It is noteworthy that the earliest varieties (Delbard Estival and Gala) generally showed the highest antioxidant capacity. Variations in antioxidant capacity between varieties of cultivated apple have also been observed by Imeh and Khokhar,[17] McGhie et al.,[10] Vieira et al.,[18] and Wojdylo et al.[5]

Very weak correlations were observed among total phenolics, ascorbic acid, and the ORAC value for apples and pears, except between the ORAC value and the ascorbic acid content in pears ($R^2 = 0.502$).

3.2. Antioxidant Capacity and Phenolic and Ascorbic Acid Contents of Various Pear Cultivars. The antioxidant capacity (ORAC assay) of pears was found to vary between 4251 ± 221 μmol TE/100 g FW (Durondeau) and 1468 ± 121 μmol TE/100 g FW (Beurre Alexander Lucas) (Table 2). This range of variation was similar to that found for apples. The phenolic content varied from 109 ± 10 mg/100 g FW (Doyenne de Comice) to 304 ± 14 mg/100 g FW (Durondeau) and the ascorbic acid content from 7.5 ± 0.5 mg/100 g FW (Triomphe de Vienne) to 29.7 ± 1.0 mg/100 g FW (Sweet Sensation). The magnitude of these variations was similar to that found for apples. For the first four varieties of Table 2, the antioxidant capacity correlated very well ($r^2 = 0.99$) with the phenolic content, as observed by Sanchez et al.,[19] while ascorbic acid made only a small contribution to the total antioxidant capacity of pears.

3.3. Harvest Time. Apples or pears harvested at the same degree of maturity showed no significant differences in antioxidant capacity, total phenolics, or ascorbic acid content according to the date of harvest (Figure 1). In pears, Lentheric et al.[20] found a late harvest date to be accompanied by a decline in the nonenzymatic and enzymatic systems responsible for the catabolism of active oxygen species, but in their work, the pears were picked before, during, and after the estimated ideal time for commercial harvest. In our experiments, the apples and pears were all harvested at the ideal state for commercial use, but we used varieties where not all fruits arrived at this state at the same time. For King Jonagold apples and Conference pears, respectively, 3 and 2 harvests were carried out, at about 2-week intervals (Figure 1). In conclusion, the state of the fruit at harvest may be important but not the date of harvest during the season for fruits having reached the same degree of ripeness.

3.4. Year-to-Year Differences. For both apples and pears, major differences in antioxidant capacity and phenolic content (up to about 65%) were observed (Figure 2) between fruits harvested on the same day in 2008 and 2009. Previously, van der Sluis et al.,[9] focusing on four apple cultivars, observed no year-to-year variation of the antioxidant activity. Year-to-year variations have been observed for some phenolic compounds, such as phloridzin[9] or cyanidin galactoside.[21] The differences observed here may be due to variations in weather conditions (temperature, humidity...) as suggested by McGhie et al.[10] but not to differences in the maturity of the fruits, which were harvested by professionals in the same state and at the same maturity stage for commercial use.

3.5. Long-Term Cold Storage. To study long-term storage, we stored apples (King Jonagold) under three sets of conditions: at 1 °C in air, at 1 °C in a controlled atmosphere (ULO, 0.9% O_2; 1.2% CO_2), and in the same controlled atmosphere after pretreatment with 1-methylcyclopropene (1-MCP). Samples stored under all three sets of conditions were analyzed after 3, 6, and 9 months, except those stored at 1 °C in air, which were not analyzed after 9 months because the fruits were no longer edible.

Total phenolics showed an increase after three months of storage in ULO conditions, followed by a decrease as under all storage conditions tested (Figure 3A). Adyanthaya et al.[22] also observed an increase in some varieties of apples after 3 months of postharvest storage. This increase appeared closely linked to α-glucosidase inhibition, suggesting that appropriately stored apples with a high phenolic content have the potential to achieve better glycemic index modulation by contributing antioxidants that can positively influence tissues susceptible to glucose-linked oxidative stress.[22] In a study by van der Sluis et al.,[9] storage in air or in a controlled atmosphere had no significant influence on the quercetin glycoside, phloridzin, or cyanidin galactoside concentration in different apple cultivars.

A major decrease (±80%) in ascorbic acid content was observed after 3 months of storage under all conditions (Figure 3B). The decrease continued over the following months. Fawbush et al.[23] also showed a decline in ascorbic acid content in apples stored in air for periods between 4.5 and 9 months, but

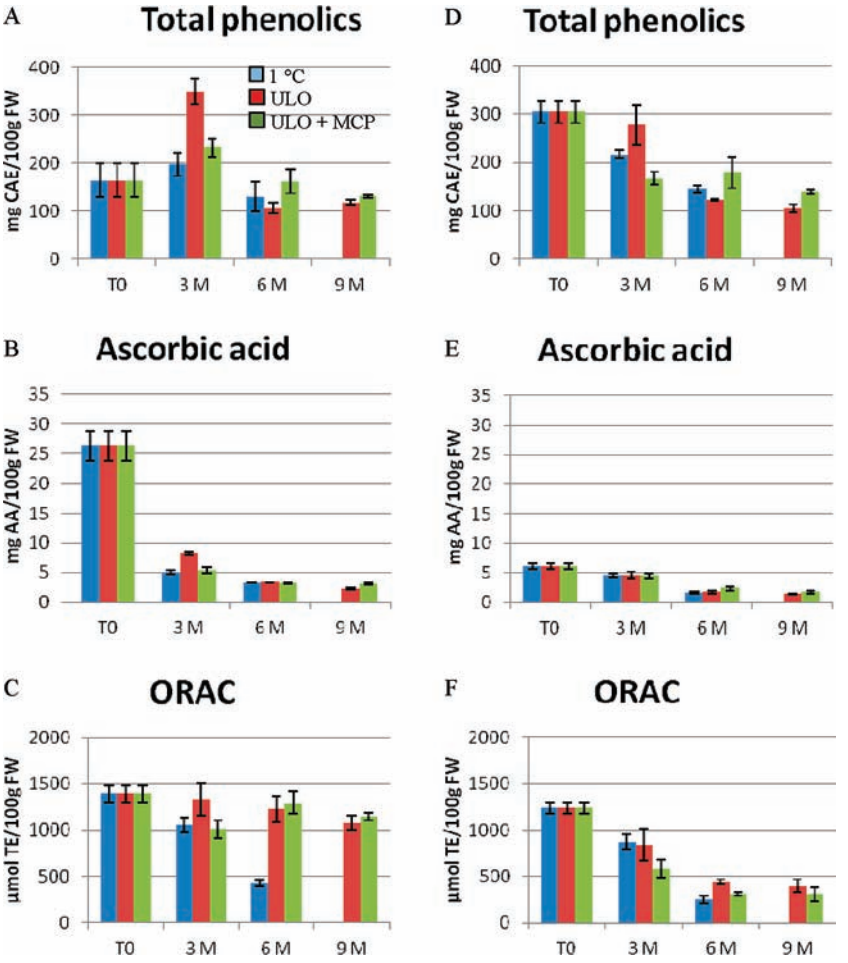

Figure 3. Antioxidant capacity (μmol TE/100 g FW), ascorbic acid content (mg AA/100 g FW), and total phenolics (mg CAE/100 g FW) in apples (King Jonagold) stored at 1 °C (blue bars), at 1 °C under ULO (red bars), and at 1 °C under ULO after 1-MCP treatment (green bars) and analyzed directly (A to C) or after one week at 20 °C (D to F).

Table 3. Antioxidant Capacity (μmol TE/100 g FW), Ascorbic Acid Content (mg AA/100 g FW), and Total Phenolics (mg CAE/100 g FW) in King Jonagold Apples (Stored for 3 Months) with and without Peel[a]

	total phenolics (mg CAE/100 g FW)	ascorbic acid (mg AA/100 g FW)	ORAC (μmol TE/100 g FW)
apple with peel	260 ± 23 a	6.2 ± 0.3 a	1134 ± 59 a
apple without peel	192 ± 19 b	±0.3 b	933 ± 25 b
peeling effect	−26%	−48%	−18%

[a] Significant differences as determined by ANOVA ($p < 0.05$) are indicated by different letters.

they observed no change in fruits stored under ULO. In pears, Zerbini et al.[24] showed that more than 50% of ascorbic acid was lost after 10 days of storage. This decrease in total ascorbic acid content in pears was especially rapid when the fruits were stored in a controlled atmosphere.[25] The loss of ascorbic acid is a marker of oxidative stress during storage. Ascorbic acid plays a major role in defense against free radicals inducing peroxidation in stressed plants. It is readily oxidized to dehydroascorbic acid, which can be either reduced, thus regenerating ascorbate, or irreversibly broken down. Storage under a controlled atmosphere induces significant metabolic changes in apples, such as a decrease in the ascorbic acid level and a transient increase in ascorbate peroxidase and glutathione reductase activities, which may partially explain the behavior of these fruits during long-term storage.[25]

The antioxidant capacity decreased rapidly in apples stored at 1 °C in air (Figure 3C). Under other storage conditions, it was stable for the 6 first months, but after 9 months under ULO, it showed a significant decrease, as observed for 4 cultivars by van der Sluis et al.[9] In keeping with the findings of Leja et al.,[26] the increase in phenolic compounds observed in our King Jonagold apples did not correlate with an increase in antioxidant capacity. This absence of correlation is likely due to a decrease in lipophilic antioxidants during storage, as measured by Matthes and Schmitz-Eiberger.[27] As in pears,[28] treatment with 1-MCP did not affect the antioxidant capacity or ascorbic acid level. In conclusion, under good storage conditions the antioxidant properties of the King Jonagold apple can be maintained for up to 6 months.

dx.doi.org/10.1021/jf201013k |J. Agric. Food Chem. 2011, 59, 6165–6171

3.6. Home Storage Conditions (20 °C). The fruits used in the previous experiment (directly after harvest or after cold storage) were subsequently stored at 20 °C for one week to simulate conditions at the consumers' home (shelf life). Fresh apples stored for one week at 20 °C showed a major increase in phenolic content (Figure 3D), probably due to temperature stress. This overall increase probably reflected different behaviors of individual phenolic compounds, as levels of some of them have been shown to increase, while levels of others decrease.[29] The fact that the skin and the flesh of the fruit evolve differently might also be responsible for the amplitude of the variations observed. In Granny Smith apples stored at 4° for 10 days, Perez-Ilzarbe et al.[30] found the concentration of phenolic compounds to increase in the skin but not in the flesh during rewarming of the fruit at 22 °C for 21 days.

A major ascorbate content decrease (±75%) was observed in the apples after 7 days at 20 °C (Figure 3E). The stress conditions linked to home storage were probably responsible for an increase in ascorbic acid catabolism, leading a rapid decrease in ascorbic acid content, as observed for cold storage.

After storage for 7 days at 20 °C, the antioxidant capacity of the apples decreased whatever the cold storage conditions (Figure 3F). Similarly, Matthes and Schmitz-Eiberger[27] report lower values for the antioxidant capacity of home-stored apples, without parallel changes in total phenolics.

3.7. Peeled Apples. The total phenolic content, the ascorbic acid content, and the antioxidant capacity were measured in whole and peeled apples (Table 3). Lower values for all parameters were observed after peeling, suggesting that most antioxidant compounds were actually located in the peel. Both the ascorbic acid content[31] and polyphenolics[32] have previously been shown to be present at higher levels in the peel than in the flesh, the ratio depending on the cultivar.[33] The (4 to 15 times) greater antioxidant activity in the peel may be due to the presence of anthocyanins such as phloridzin and quercetin glycosides (rutin).[34] Yet because the peel represents only a small percentage of the entire fruit weight (6 −8%), its significance as a contributor of phenolics is probably limited. In King Jonagold apples, peeling resulted in a 26%, 48%, and 18% decrease in phenolic content, ascorbic acid level, and antioxidant capacity, respectively.

At the individual compound level, epicatechin and procyanidin B2 were the major contributors to the antioxidant activity of apple peel, and hydroxycinnamic acids may play a significant role in the flesh.[35]

AUTHOR INFORMATION

Corresponding Author

*Tel: + 32 43 66 38 46. Fax: + 32 43 66 38 72. E-mail: c.kevers@ulg.ac.be.

Author Contributions

C.K. and J.P. contributed equally to this work.

Funding Sources

The Walloon Ministry financed this research through an "étude de faisabilité" to Belgium fruit auctions (VISE-SORT "Veiling Borgloon").

ACKNOWLEDGMENT

The "Belgische Fruitveiling" of St. Truiden provided the material. The skilful assistance of the APE personnel (provided to CEDEVIT by the government of Wallonia) is greatly appreciated.

REFERENCES

(1) Joshipura, K. J.; Hu, F. B.; Manson, J. E.; Stampfer, M. J.; Rimm, E. B.; Speizer, F. E.; Colditz, G.; Ascherio, A.; Rosner, B.; Spiegelman, D.; Willett, W. C. The effect of fruit and vegetable intake on risk for coronary heart disease. *Ann. Intern. Med.* **2001**, *134*, 1106–1114.

(2) Riboli, E.; Norat, T. Epidemiologic evidence of the protective effect of fruit and vegetables on cancer risk. *Am. J. Clin. Nutr.* **2003**, *78*, 559S–569S.

(3) Genkinger, J. M.; Platz, E. A.; Hoffman, S. C.; Comstock, G. W.; Helzlsouer, K. J. Fruit, vegetable, and antioxidant intake and all-cause, cancer, and cardiovascular disease mortality in a community-dwelling population in Washington County, Maryland. *Am. J. Epidemiol.* **2004**, *160*, 1223–1233.

(4) Manach, C.; Scalbert, A.; Morand, C.; Remesy, C.; Jimenez, L. Polyphenols: food sources and bioavailability. *Am. J. Clin. Nutr.* **2004**, *79*, 727–747.

(5) Wojdylo, A.; Oszmianski, J.; Laskowski, P. Polyphenolic compounds and antioxidant activity of new and old apple varieties. *J. Agric. Food Chem.* **2008**, *56*, 6520–6530.

(6) Kevers, C.; Falkowski, M.; Tabart, J.; Defraigne, J. O.; Dommes, J.; Pincemail, J. Evolution of antioxidant capacity during storage of selected fruits and vegetables. *J. Agric. Food Chem.* **2007**, *55*, 8596–8603.

(7) Macheix, J.; Fleuriet, A.; Billot, J. *Fruit Phenolics*; CRC Press: Boca Raton, FL, 1990

(8) Jiang, H.; Ji, B. P.; Liang, J. F.; Zhou, F.; Yang, Z. W.; Zhang, G. Z. Changes of contents and antioxidant activities of polyphenols during fruit development of four apple cultivars. *Eur. Food Res. Technol.* **2006**, *223*, 743–748.

(9) van der Sluis, A. A.; Dekker, M.; de Jager, A.; Jongen, W. M. F. Activity and concentration of polyphenolic antioxidants in apple: Effect of cultivar, harvest year, and storage conditions. *J. Agric. Food Chem.* **2001**, *49*, 3606–3613.

(10) McGhie, T. K.; Hunt, M.; Barnett, L. E. Cultivar and growing region determine the antioxidant polyphenolic concentration and composition of apples grown in New Zealand. *J. Agric. Food Chem.* **2005**, *53*, 3065–3070.

(11) Rossle, C.; Wijngaard, H. H.; Gormley, R. T.; Butler, F.; Brunton, N. Effect of storage on the content of polyphenols of minimally processed skin-on apple wedges from ten cultivars and two growing seasons. *J. Agric. Food Chem.* **2010**, *58*, 1609–1614.

(12) Tabart, J.; Kevers, C.; Sipel, A.; Pincemail, J.; Defraigne, J. O.; Dommes, J. Optimisation of extraction of phenolics and antioxidants from black currant leaves and buds and of stability during storage. *Food Chem.* **2007**, *105*, 1268–1275.

(13) Tabart, J.; Kevers, C.; Pincemail, J.; Defraigne, J. O.; Dommes, J. Antioxidant capacity of black currant varies with organs, season and cultivars. *J. Agric. Food Chem.* **2006**, *54*, 6271–6276.

(14) Wu, X. L.; Beecher, G. R.; Holden, J. M.; Haytowitz, D. B.; Gebhardt, S. E.; Prior, R. L. Lipophilic and hydrophilic antioxidant capacities of common foods in the United States. *J. Agric. Food Chem.* **2004**, *52*, 4026–4037.

(15) Association of Vitamin Chemists. *Methods of Vitamin Assay*, 3rd ed.; Interscience Publishers: New York, 1961.

(16) Vrhovsek, U.; Rigo, A.; Tonon, D.; Mattivi, F. Quantitation of polyphenols in different apple varieties. *J. Agric. Food Chem.* **2004**, *52*, 6532–6538.

(17) Imeh, U.; Khokhar, S. Distribution of conjugated and free phenols in fruits: Antioxidant activity and cultivar variations. *J. Agric. Food Chem.* **2002**, *50*, 6301–6306.

(18) Vieira, F. G. K.; Borges, G. D. C.; Copetti, C.; Amboni, R.; Denardi, F.; Fett, R. Physico-chemical and antioxidant properties of six apple cultivars (*Malus domestica* Borkh) grown in southern Brazil. *Sci. Hortic. (Amsterdam, Neth.)* **2009**, *122*, 421–425.

(19) Sanchez, A. C. G.; Gil-Izquierdo, A.; Gil, M. I. Comparative study of six pear cultivars in terms of their phenolic and vitamin C contents and antioxidant capacity. *J. Sci. Food Agric.* **2003**, *83*, 995–1003.

(20) Lentheric, I.; Pinto, E.; Vendrell, M.; Larrigaudiere, C. Harvest date affects the antioxidative systems in pear fruits. *J. Hortic. Sci. Biotechnol.* **1999**, *74*, 791–795.

(21) Awad, M. A.; de Jager, A. Flavonoid and chlorogenic acid concentrations in skin of 'Jonagold' and 'Elstar' apples during and after regular and ultra low oxygen storage. *Postharvest Biol. Technol.* **2000**, *20*, 15–24.

(22) Adyanthaya, I.; Kwon, Y. I.; Apostolidis, E.; Shetty, K. Health benefits of apple phenolics from postharvest stages for potential type 2 diabetes management using in vitro models. *J. Food Biochem.* **2010**, *34*, 31–49.

(23) Fawbush, F.; Nock, J. F.; Watkins, C. B. Antioxidant contents and activity of 1-methylcyclopropene (1-MCP)-treated 'Empire' apples in air and controlled atmosphere storage. *Postharvest Biol. Technol.* **2009**, *52*, 30–37.

(24) Zerbini, P. E.; Rizzolo, A.; Brambilla, A.; Cambiaghi, P.; Grassi, M. Loss of ascorbic acid during storage of Conference pears in relation to the appearance of brown heart. *J. Sci. Food Agric.* **2002**, *82*, 1007–1013.

(25) Larrigaudiere, C.; Lentheric, I.; Pinto, E.; Vendrell, M. Short-term effects of air and controlled atmosphere storage on antioxidant metabolism in conference pears. *J. Plant Physiol.* **2001**, *158*, 1015–1022.

(26) Leja, M.; Mareczek, A.; Ben, J. Antioxidant properties of two apple cultivars during long-term storage. *Food Chem.* **2003**, *80*, 303–307.

(27) Matthes, A.; Schmitz-Eiberger, M. Polyphenol content and antioxidant capacity of apple fruit: effect of cultivar and storage conditions. *J. Appl. Bot. Food Qual.* **2009**, *82*, 152–157.

(28) Silva, F. J. P.; Gomes, M. H.; Fidalgo, F.; Rodrigues, J. A.; Almeida, D. P. F. Antioxidant properties and fruit quality during long-term storage of "rocha" pear: effects of maturity and storage conditions. *J. Food Qual.* **2010**, *33*, 1–20.

(29) Awad, M. A.; de Jager, A. Influences of air and controlled atmosphere storage on the concentration of potentially healthful phenolics in apples and other fruits. *Postharvest Biol. Technol.* **2003**, *27*, 53–58.

(30) Perez-Ilzarbe, J, H., T.; Estrella, I; Vendrell, M. Cold storage of apples (cv. Granny Smith) and changes in phenolic compounds. *Z. Lebensm. Unters. Forsch.* **1997**, *204*, 52–55.

(31) Felicetti, E.; Mattheis, J. P. Quantification and histochemical localization of ascorbic acid in 'Delicious', 'Golden Delicious', and 'Fuji' apple fruit during on-tree development and cold storage. *Postharvest Biol. Technol.* **2010**, *56*, 56–63.

(32) Wolfe, K.; Wu, X. Z.; Liu, R. H. Antioxidant activity of apple peels. *J. Agric. Food Chem.* **2003**, *51*, 609–614.

(33) Yuri, J. A.; Neira, A.; Quilodran, A.; Motomura, Y.; Palomo, I. Antioxidant activity and total phenolics concentration in apple peel and flesh is determined by cultivar and agroclimatic growing regions in Chile. *J. Food Agric. Env.* **2009**, *7*, 513–517.

(34) Lata, B.; Trampczynska, A.; Paczesna, J. Cultivar variation in apple peel and whole fruit phenolic composition. *Sci. Hortic. (Amsterdam, Neth.)* **2009**, *121*, 176–181.

(35) Tsao, R.; Yang, R.; Xie, S.; Sockovie, E.; Khanizadeh, S. Which polyphenolic compounds contribute to the total antioxidant activities of apple? *J Agric. Food Chem.* **2005**, *53*, 4989–4995.