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# Antioxidant Capacity and Phenolic Content of Selected Strawberry Genotypes

**Djamila Rekika, Shahrokh Khanizadeh,[1] Martine Deschênes, Audrey Levasseur, and Marie Thérèse Charles**

*Agriculture and Agri-Food Canada, Horticultural Research and Development Centre, 430 Boulevard Gouin, St-Jean-sur-Richelieu, QC, Canada, J3B 3E6*

**Rong Tsao and Raymond Yang**

*Agriculture and Agri-Food Canada, Food Research Centre, 93 Stone Road West, Guelph, ON, Canada, N1G 5C9*

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***Abstract.*** **Eighteen strawberry genotypes were evaluated for their phenolic content and antioxidant capacity using several methods. High antioxidant capacity was found for 'Harmonie', 'Saint-Jean d'Orléans', and 'Saint-Laurent d'Orléans', which were reported to have better shelf life than 'Kent'. 'Harmonie', 'Saint-Jean d'Orléans', 'Orléans', and some advanced selections had higher hydroxycinnamic acids, benzoic acids, and flavonols than 'Kent'. The significant variation in antioxidant capacity and total phenolic compounds clearly shows the potential value of certain new cultivars and advanced lines as parents in a breeding program. The future plan is to examine individual antioxidant and their role in disease resistance and extension of shelf life and to use selected genotypes as parents to developed new lines.**

For the past few years, growing interest has been devoted to the phytochemical content of raspberry (*Rubus idaeus* L.*)*, blueberry (*Vaccinium* sp.), strawberry (*Fragaria ananassa* Deuch.) and other fruits (Clark et al., 2002; Maas et al., 1991; Kalt et al., 2001; Prior et al., 1998; Wang and Lin 2000) and specific attention has been given to the antioxidant capacity of these fruits. Conclusive evidences were drawn from the cited studies demonstrating that antioxidant vitamins such as vitamin C, vitamin E, or β-carotene were not the only compounds responsible for the antioxidant capacity of the studied fruits and vegetables. Other studies showed that antioxidant activity of plant extracts, like grape (*Vitis vinifera* L.), blueberry and strawberry was correlated with total phenolic content rather than with any individual phenolic compound (Meyer et al., 1997; Prior et al., 1998; Wang et al., 1997). In strawberry fruit, ellagic acid along with some flavonoids (anthocyanins, proanthocyanins, catechin and isocatechin) are the main compounds with antioxidant properties. These compounds are known to influence quality, acceptability and stability of foods by acting as flavorants, colorants or antioxidants (Maas et al., 1991).

The antioxidant capacity and the composition of bioactive compounds in fruits and vegetables are influenced by several factors of which the most commonly cited are cultural practices, preharvest conditions (climate, temperature), maturity, post-harvest handling and processing (Clark et al., 2002; Kalt et al., 2001; Prior et al., 1998; Saure, 1990; Wang and Zheng, 2001; Wang et al*.,* 2002). Substantial variation has been observed in strawberry for ellagic acid content (Funt et al., 2001) and in blueberry for antioxidant capacity and anthocyanin content (Clark et al., 2002; Kalt and McDonald 1996; Kalt et al., 1999). Antioxidant composition of strawberry varies among cultivars and also with development stage and tissue specificity (Kosar et al., 2004, Maas et al., 1991, Ménager et al., 2004; Olsson et al*.,* 2004). Pulp of immature strawberry fruit was found to contain about twice as much ellagic acid as red fruit pulp and, higher concentration was found in achenes compared to fruit pulp and leaf tissue. Wang and Lin (2000) studied the total antioxidant capacity in strawberry, raspberry and blackberry and reported it as oxygen radical absorbance capacity (ORAC). Their results showed that blackberries and strawberries had higher ORAC activity at the green stage compared to raspberries, and that the anthocyanin content of strawberries and blackberries increased with maturity.

Kalt and co-workers (2001) showed an increase in anthocyanin content and ORAC activity of strawberry and raspberry during 8 d of storage at temperatures higher than 0 °C. In highbush blueberries (*Vaccinium corymbosum* L.), Kalt et al. (2003) reported lower phenolic content and ORAC activity in the ripe fruit.

Molecules with antioxidant properties play significant roles in several biological processes that sustain life and defense against external stresses. In plant organs, oxidative stress is involved in physiological processes such as fruit ripening and senescence (Brennan and Frenkel, 1977; Rogier et al., 1998). Free radicals through the induction of lipid peroxidation play an important role in senescence and ageing process. High levels of cellular antioxidants, particularly of reducing enzymes, were demonstrated to delay senescence in fruit and vegetables species such as muskmelon (*Cucumis melo* L.), sweet peppers (*Capsicum annuum* L.) and spinach (*Spinacia oleracea* L.) (Lancan and Baccou, 1998; Masia, 1998; Miyake et al., 1998). It has been shown that phenolic compounds play an important role in plant defense mechanisms against field and post-harvest infection or injuries (Mayr et al., 1997; Wang et al., 1994). A 3-fold increase in ellagic acid content was observed in raspberry leaves infected by orange rust (*Arthuriomyces peckianus*) (Wang et al., 1994); and high level of catechins, the main constitutive unit of proanthocyanidins (PA), found in immature strawberry fruits was associated with resistance to grey mold (*Botrytis cinerea* Pers. ex. Fr.) (Di Venere et al., 1998; Feucht et al., 1992; Jersch et al., 1989). In vitro studies revealed that proanthocyanidins of some strawberry cultivars reduced hyphal growth of grey mold and, fruits of such cultivars high in PA content were more resistant to storage rot development (Hébert et al., 2002).

As underlined by several authors, the antioxidant profile of fruits and vegetables need to be considered in breeding programs, along with field performance and responses of the selections to cultural practices as well as harvest and post-harvest storage strategies (Asami et al., 2003; Gao et al., 2000; Maas et al., 1991; Strålsjö et al*.,* 2003; Wang et al*.,* 2002).

The purpose of this study was to evaluate antioxidant activity and phenolic content of selected cultivars and advanced strawberry selections to find cultivars high in antioxidants for use as parents in future strawberry breeding program.

## Materials and Methods

*Chemicals.* Phenolic standards and tetramethyl chroman carboxylic acid were purchased from Sigma Chemical Co. (Oakville, Ontario); ellagic acid, gallic acid, *p*-coumaric acid, sodium carbonate ($Na_2CO_3$) and the Folin-Ciocalteu reagent were purchased from Sigma Chemical Co. (St. Louis, Mo.); quercetin-3-galactoside was from Fluka Chemie GmbH (Buchs, Switzerland); and cyanidin-3-galactoside was from Indofine Chemical Co. (Hillsborough, N.J.). Water used for HPLC analysis was purified in-house from distilled and deionized water using a NanoPure system (Dubuque, Iowa). All other HPLC grade solvents were purchased from Caledon Laboratories Ltd (Georgetown, Ontario).

*Sample preparation and extraction procedures.* Fruit samples from 18 strawberry genotypes (*Fragaria ×ananasa Deuch.)* were collected from a completely randomized design with four replications established in Agriculture and Agri-Food Canada experimental farm, located at l'Acadie (longitude 73.35 W; latitude 45.32 N), Quebec. Fruit (0.5 kg fresh weight per replication) were harvested at optimum

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[1]To whom all correspondence should be addressed; e-mail khanizadehs@em.agr.ca.

maturity in July 2003. Samples were rapidly cooled to 1 °C, brought to the laboratory where they were cut in half, frozen in liquid nitrogen and three subsamples of 150 g of each genotype were stored at –80 °C until extraction. Samples were lyophilised in Lyo-Tech freeze-dryer (Lyo-San Inc., Quebec, Canada), and an aliquot of each subsample was used to determine the average dry/fresh matter ratio of 10%. Freeze dried samples were reduced to a fine powder with a commercial coffee grinder and stored at –20 °C until analysis.

All data were subjected to an Analysis of Variance (ANOVA) using GLM and CORR procedure of SAS (1989). The means were separated using the least significant difference (LSD) test at 0.05 level.

*Freeze-dried samples.* Ground freeze-dried sample (1 g) was homogenized in a blender (Power Gen 700) for 2.5 min with 50 mL deionized water on ice (4 °C). Three extracts were prepared according to the procedure described by Gao et al. (2000). Briefly, 5 mL of the original homogenized sample were diluted with 1 mL of 95% EtOH. The mixture was centrifuged at 4 °C (4500 rpm, 15 min), and the clear supernatant was collected as crude extract. The aqueous and lipophilic extracts were obtained after partitioning with 95% ethanol and hexane.

The original homogenized sample (5 mL) was also diluted with 1 mL of EtOH 95% and extracted twice with hexane (2 × 4 mL). The hexane phase was dried under nitrogen, redissolved in 6 mL of EtOH 95% and used as lipophilic extract. The aqueous phase was then centrifuged at 4 °C and at 4500 rpm for 15 min. Strawberry samples of this extraction procedure were used for ABTS cation radical-scavenging assay.

*Frozen samples*. Ten grams (10 g) of fresh-frozen fruit were blended in 50 mL of 50% methanol using a Polytron blender (Brinkmann Instruments, New York). The mixture was filtered through filter paper (Whatman no. 1) and through a 0.45-µm Acrodisc syringe filter (Gelman Lab., Michigan). The final filtrate was then stored at –20 °C before being analyzed. Extracts resulting from this procedure were used in total phenolic content, ferric reducing/antioxidant power (FRAP) and HPLC assays.

*ABTS cation radical-scavenging assay.* The ABTS (2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) free-radical-scavenging assay was conducted as described by Pellegrini et al. (1999). ABTS stock solution was prepared by mixing 5 mL of 7 mM (ABTS) with 88 µL of 140 mM $K_2S_2O_8$. The stock solution was diluted with 95% EtOH to give an absorbance of 0.7 ± 0.05 at 734 nm. Strawberry extracts (5 µL of 16 mg·mL$^{-1}$) were mixed with 1 mL ABTS reagent and measured at 734 nm (Beckman 600) after 30 min at room temperature. Trolox (a water soluble vitamin E analogue) was used as a standard and the capacity of free radical scavenging was expressed as µmol trolox equivalents (TE) per gram of dry matter (µmol·g$^{-1}$).

*Ferric reducing/antioxidant power assay.* The FRAP was determined according to the method of Benzie and Strain (1996) which was modified for the 96-well microplate reader (Tsao et al., 2003a). $FeSO_4$ was used as standard and the FRAP value of the samples was calculated on the basis of 500 µM $Fe^{2+}$ ($FeSO_4$•$7H_2O$).

*Total phenolic content.* Total phenolic content was determined according to the Folin-Ciocalteu (FC) method (Slinkard and Singleton, 1977) with slight modifications. Briefly, the standard or sample extract (0.2 mL) were mixed with 1.0 mL of Folin-Ciocalteu reagent and 0.8 mL of $Na_2CO_3$ (7.5%) and allowed to stand for 30 min at room temperature. Absorption was measured at 765 nm in a spectrometer (Cary 3C; Varian Canada Inc., Ontario). Gallic acid was used as a standard and the total phenolic content was expressed as gallic acid equivalents (GAE) in µg·g$^{-1}$ of fresh-frozen fruit.

*Phytochemical content (HPLC).* The phenolic composition of berries was analyzed by HPLC as described by Tsao and Yang (2003). The injection volume was 20 µL for all samples. All standards except for anthocyanins were dissolved in methanol. The latter were dissolved in 1% HCl in methanol. The detector was set at 254, 280, 320, 360, and 520 nm for simultaneous monitoring of the different groups of phenolics.

Total phenolic compounds were divided into five groups, as follows: anthocyanins were quantified using cyanidin-3-galactoside (520 nm), hydroxycinnamic acids were quantified using p-coumaric acid (320 nm), flavonols were quantified using quercetin-3-galactoside (360 nm), for ellagic acid the authentic standard was used (254 nm) and benzoic acids were quantified using gallic acid (280 nm) (Tsao et al., 2003b; Wang et al., 2002). The results were expressed as µg·g$^{-1}$ fresh-frozen fruit.

## Results

*ABTS cation radical-scavenging assay.* Significant differences in TEAC were observed among the selected genotypes (Table 1). For all genotypes, the antioxidant capacity measured by the ABTS cations radical-scavenging assay was higher for the crude and aqueous extracts than for lipophilic ones (Table 1). Total antioxidant capacity ranged from 198.8 to 272.4 µmol·g$^{-1}$ and 214.3 to 263.1 µmol·g$^{-1}$ of TE for the crude and aqueous extracts, respectively. Total antioxidant capacity of the lipophilic extracts varied from 26.0 to 40.3 µmol·g$^{-1}$ of TE. The highest TEAC value of crude extracts was found for genotypes 'APF9335-26' (272.4 µmol·g$^{-1}$), and 'Jewel' (269.5 µmol·g$^{-1}$), while 'Kent' had the lowest TEAC (198.8 µmol·g$^{-1}$).

Similar to the crude extracts, the highest TEAC of aqueous extracts were recorded for 'APF9335-26' and 'Jewel' (263.1 and 259.3 µmol·g$^{-1}$) followed by 'Orléans' and 'FIO996-2' with an equivalent amount (Table 1). In contrast, low antioxidant capacity was found for 'Clé des Champs' and 'SJ8976-1' genotypes (214.3 and 217.9 µmol·g$^{-1}$, respectively). The genotypes 'FIO9917-25', 'Saint-Jean d'Orléans', and 'Saint Pierre' were intermediate for both crude and aqueous extracts. The lipophilic extracts showed the lowest activity when compared to the other extracts but showed greater variation among genotypes. The TEAC value from 'Saint-Laurent d'Orléans' and 'Jewel' was significantly higher (40.3 and 39.9 µmol·g$^{-1}$, respectively), than that of 'Harmonie' (26.0 µmol·g$^{-1}$).

*Ferric reducing/antioxidant power assay.* Great differences ($p < 0.0001$) among genotypes were found in their ferric reducing ability (Table 1). On the basis of the standard ($Fe^{2+}$), 'FIO9923-7', 'APF9335-26' and 'Jewel' genotypes showed the highest antioxidant activity (2984, 2963, and 2874 µM FRAP, respectively). Conversely, 'Kent' had the lowest activity with 2131 µM FRAP. For most of the remaining genotypes, FRAP values varied between 2400 and 2200 µM (Table 1).

*Total phenolic content.* Significant differences were observed between the genotypes tested ($p < 0.0001$) in total phenolic content. The total phenolic content ranged from 426.5 to 937.1 µg·g$^{-1}$. Fruit of 'Jewel', 'Harmonie', 'APF9335-26', 'Saint-Laurent d'Orléans', 'FIO9923-7' and 'Clé des Champs' had the highest total phenolic content with >800 µg·g$^{-1}$ (Table 1), whereas 'FIO9917-25' selection had the lowest total phenolic content with less than 500 µg·g$^{-1}$. The remaining genotypes were intermediate with a total phenolic content varying between 550 and 850 µg·g$^{-1}$ (Table 1).

There was a positive correlation between FRAP and total phenolic content of the fruits ($r = 0.6599$, $p < 0.05$). The higher total phenolic content in fruits resulted in higher total antioxidant activity. However, a weak correlation was observed between TEAC (crude extract) and total phenolic content ($r = 0.4438$, $p < 0.05$). A positive correlation was also noted between FRAP and TEAC (crude extract) antioxidant capacity ($r = 0.6625$, $p < 0.05$).

*Phenolic composition.* Among the five groups, the anthocyanins were the most predominant phenolic compounds in strawberry extracts (67.2% of the total phenolics) (Table 2). Once again, 'Jewel' contained up to 800 µg·g$^{-1}$ (cyanidin-3-galactoside equivalent) followed by 'Clé des Champs' and 'APF9926-27' with 686.79 and 659.31 µg·g$^{-1}$. The lowest values were found for 'APF9335-26', 'FIO9917-25' and 'SJ8976-1' (190.5, 245.5 and 252.33 µg·g$^{-1}$, respectively).

Benzoic acids were the second group in abundance with 16.8% of the total phenolics. 'FIO9917-25' and 'APF9335-26' had the highest content of benzoic acids (245.58 and 211.47 µg·g$^{-1}$ gallic acid equivalent, respectively).

Hydroxycinnamic acids group levels ranged between 143.91 to 16 µg·g$^{-1}$, with the highest amounts being recorded in 'Harmonie' and 'APF9323-7' (143.91 and 141.96 µg·g$^{-1}$ p-coumaric acid equivalent) followed by 'FIO9913-29', 'SJ8976-1', and 'Orléans' (Table 2). The lowest amount was measured in 'FIO9917-25' (16.38 µg·g$^{-1}$).

Flavonols content ranged from 51.78 to 11.55 µ·g$^{-1}$ quercetin-3-galactoside equivalent and ellagic acid from 33.96 to 14.31 µg·g$^{-1}$. These two groups recorded the lowest contribution with 4.8% and 3% of the total pheno-

lics, respectively. 'FIO996-2', 'FIO9923-7', 'APF9926-27', 'APF9323-7', 'Harmonie', and 'Saint-Jean d'Orléans' had higher flavonols amount while 'APF9335-26' and 'Saint-Jean d'Orléans' showed the highest and the lowest ellagic acid amount, respectively.

The amount of total phenolics in the frozen fruits analyzed by HPLC ranged between 1014.99 and 482.94 $\mu g \cdot g^{-1}$. The highest total phenolics content was found for 'Jewel' followed by 'Clé des Champs', 'APF9926-27', 'APF9323-7' and 'Harmonie' (Table 2).

No correlation was found between ellagic acid, anthocyanins content and total antioxidant capacity (TEAC, FRAP).

## Discussion

Crude extract contained both hydrophilic (aqueous extract) and lipophilic antioxidants. As illustrated in the present study, the aqueous extract markedly contributes to the total antioxidant capacity and could be related to the total phenolic content. A positive correlation between free phenolics and total antioxidant activity in a number of different fruit has been reported (Kalt et al., 2003; Wang and Lin, 2000). In our study phenolics account for a major portion of the total antioxidant activity of strawberries ($r = 0.6599$, $p < 0.05$).

The contents of total phenolics, as determined by the FC assay, for the fruit extract analyzed here, were in the same range (86 mg GAE/100g FW) of those reported by Kalt et al. (1999). However, they were relatively lower than those reported by Tsao et al. (2003b) and Funt et al. (2001), whereas the FRAP values were in the range of reported results. The large differences in total phenolic content are probably due to the different genotypes used. Wang and Lin (2000) reported that the total phenolic content in different varieties of ripe strawberry fruit ranged from 95 to 152 mg GAE/100 g FW.

The literature provides variable figures for the total antioxidant capacity of strawberry fruit

Table 1. Antioxidant capacity and total phenolic content of 8 cultivars and 10 advanced strawberry selections grown at the L'Acadie site.

| | Total antioxidant capacity[z] | | | | Content |
|---|---|---|---|---|---|
| | TEAC[y] (μmol TE/g) | | | FRAP[x] (μM) | Total phenolic[w] (μg GAE/g) |
| Genotype | Crude | Aqueous | Lipophilic | Crude | Crude |
| Saint-Jean d'Orléans | 227.4 | 234.7 | 29.5 | 2044.9 | 647.1 |
| Saint-Laurent d'Orléans | 242.5 | 248.0 | 40.3 | 2478.4 | 836.5 |
| Orléans | 202.0 | 259.1 | 27.8 | 2164.5 | 629.9 |
| Clé des Champs | 225.9 | 214.3 | 29.1 | 2622.7 | 804.3 |
| Harmonie | 239.9 | 224.4 | 26.0 | 2752.2 | 857.0 |
| Saint Pierre | 232.9 | 232.7 | 32.5 | 2194.8 | 598.2 |
| Jewel | 269.5 | 259.3 | 39.9 | 2873.9 | 937.1 |
| Kent | 198.8 | 228.6 | 29.7 | 2131.5 | 636.3 |
| FIO9917-25 | 222.8 | 241.4 | 28.8 | 2181.8 | 426.5 |
| FIO9926-47 | --- | --- | --- | 2364.2 | 663.3 |
| FIO9913-29 | --- | --- | --- | 2280.3 | 593.5 |
| FIO9923-7 | --- | --- | --- | 2984.3 | 808q.0 |
| FIO996-2 | 252.1 | 259.4 | 31.3 | 2686.1 | 731.2 |
| APF9926-27 | --- | --- | --- | 2425.9 | 762.3 |
| APF937-1 | 208.2 | 230.9 | 27.8 | --- | --- |
| APF9335-26 | 272.4 | 263.1 | 35.8 | 2963.1 | 856.7 |
| SJ8976-1 | 239.5 | 217.9 | 26.9 | 2458.7 | 708.1 |
| APF9323-7 | --- | --- | --- | 2546.0 | 742.2 |
| LSD 5% | 43.8 | 31.5 | 5.88 | 319 | 154 |
| $P > F$ | <0.0002 | 0.0034 | 0.0002 | <0.0001 | <0.0001 |

[z]Values are means of three to four replications.
[y]TEAC = trolox equivalent antioxidant capacity expressed as μmol trolox equivalents (TE) per g dry matter.
[x]FRAP = ferric-reducing antioxidant power expressed as μM FRAP.
[w]Total phenolic expressed as μg gallic acid equivalents (GAE) per g fresh-frozen fruit.

Table 2. Phenolic composition ($\mu g \cdot g^{-1}$ fresh-frozen fruit) in eight cultivars and nine advanced strawberry selections grown at the L'Acadie site.

| Genotype | Total anthocyanins (520 nm) | Total hydroxycinnamic acids (320 nm) | Total flavonols (360 nm) | Ellagic acid (254 nm) | Total benzoic acids (280 nm) | Total phenolics Sum of five groups |
|---|---|---|---|---|---|---|
| Saint-Jean d'Orléans | 363.39 | 42.27 | 43.11 | 14.31 | 84.09 | 547.17 |
| Saint-Laurent d'Orléans | 427.85 | 29.10 | 28.98 | 22.68 | 38.40 | 587.01 |
| Orléans | 392.19 | 86.97 | 15.21 | 19.69 | 116.07 | 629.13 |
| Clé des Champs | 686.79 | 35.31 | 26.85 | 15.81 | 163.14 | 927.90 |
| Harmonie | 463.41 | 143.91 | 45.21 | 21.90 | 82.47 | 756.84 |
| Saint Pierre | 448.74 | 54.93 | 29.97 | 16.65 | 56.13 | 606.42 |
| Jewel | 841.26 | 26.01 | 38.37 | 15.75 | 93.63 | 1014.99 |
| Kent | 622.89 | 23.97 | 25.38 | 23.76 | 64.56 | 760.53 |
| FIO9917-25 | 245.55 | 16.38 | 18.48 | 19.59 | 245.58 | 545.61 |
| FIO9926-47 | 542.43 | 65.19 | 40.83 | 20.28 | 73.29 | 742.02 |
| FIO9913-29 | 364.89 | 92.88 | 29.73 | 20.43 | 117.84 | 625.77 |
| FIO9923-7 | 497.94 | 50.55 | 50.46 | 22.02 | 102.36 | 723.36 |
| FIO996-2 | 509.10 | 22.83 | 51.78 | 22.62 | 124.74 | 731.10 |
| APF9926-27 | 659.31 | 54.99 | 47.07 | 19.08 | 77.25 | 857.70 |
| APF9335-26 | 190.50 | 27.90 | 19.11 | 33.96 | 211.47 | 482.94 |
| SJ8976-1 | 252.33 | 90.03 | 11.55 | 23.91 | 148.98 | 526.83 |
| APF9323-7 | 405.75 | 141.96 | 43.83 | 19.41 | 175.50 | 786.42 |
| Mean | 465.55 | 61.70 | 33.29 | 20.78 | 116.21 | 693.20 |
| Percent | 67.2 | 8.0 | 4.8 | 3.0 | 16.8 | 100 |
| LSD 5% | 39.07 | 10.1 | 5.34 | 2.18 | 9.32 | 40.08 |

[z]Phenolic groups were quantified as follows: ellagic acid as ellagic acid, benzoic acids as gallic acid, hydroxycinnamic acids as p-coumaric acid, flavonols as quercetin-3-galactoside, and anthocyanins as cyanidin-3-galactoside.

assessed by the ORAC method. The values of 15.4 μM TE/g FW is an accepted average figure for strawberry fruit (Wang et al., 1996) and 20 μM TE/g FW was reported for 'Kent' (Prior et al., 1998). Of the total antioxidant capacity reported by Wang et al. (1996) vitamin C contributed for <15%.

Our preliminary chemical analysis of the fruits using HPLC analysis revealed that anthocyanins (cyaniding-3-glucoside, pelargonidin-3-glucoside) were the most predominant phenolics group in strawberry extracts, followed by benzoic acids (p-hydroxybenzoic, gallic acids), hydroxycinnamic acids (p-coumaric acid, ferulic acid), flavonols (quercetin-3-galactoside) and ellagic acid groups.

A high variation of phenolic contents of strawberry cultivars was found in the literature. Our results show that anthocyanins, ellagic acid, flavonol and hydroxycinnamic acids levels were relatively similar to those reported in strawberry by Wang et al. (2002) and Meyers et al. (2003), but they were higher than those reported for ripe strawberries (Kosar et al., 2004).

No correlation was obtained between individual phenolic compound (especially anthocyanins and ellagic acid) and total antioxidant activity (TEAC, FRAP). Similar results were found by Meyers et al. (2003) in strawberries. They concluded that it was probably due to the other unquantified phenolics and/or synergism among these compounds and major phenolics. On the other hand, several studies showed that principal antioxidant activity of grape, blueberry and strawberry correlated to total phenolics and anthocyanins rather than to any individual compound, independent of the assays used (Prior et al., 1998; Wang and Lin 2000). According to Macheix et al. (1990), strawberries contain numerous phenolic compounds, and not all cultivars contain the same phenolic profile. Furthermore they reported relative proportions of compounds within the profile and differences within these profiles might subsequently result in complex changes in antioxidant activity or other bioactivities.

It is generally accepted that antioxidants act to extend shelf life and enhance quality preservation of fresh fruit by delaying senescence induced by oxidative degradation (Brennan and Frenkel, 1977; Lancan and Baccou, 1998; Masia, 1998; Miyake et al., 1998; Rogier et al., 1998). High levels of cellular antioxidants are presumed to play an important role in delayed senescence observed in nonnetted muskmelon fruits (Lacan and Baccou, 1998). The fruit of 'Orléans' has a very good shelf life of over 5 d at 4 °C (Khanizadeh et al., 2003), and the preliminary study on this cultivar indicate higher levels of free epicatechin, bound catechin, epicatechin and ellagic acid (Hébert et al., 2002). In the present study, high antioxidant capacity (TEAC and FRAP) was found for 'Harmonie', 'Saint-Jean d'Orléans' and 'Saint-Laurent d'Orléans', which exhibit better shelf life stability than 'Kent' (Khanizadeh et al., 2005; Khanizadeh, 2003a, 2003b, 2003c). It seems that there might be an association between antioxidant capacity and postharvest quality preservation as demonstrated for other crops (Baldwin et al., 1995; Khan et al., 1999; Lancan and Baccou, 1998; Masia, 1998; Miyake et al., 1998), however this is not always straight forward. For example 'Saint Pierre' characterized by very good shelf life (Khanizadeh et al., 2002) displayed similar level of antioxidants (gallic acid, epicatechin, catechin and ellagic acid) to other cultivars with shorter shelf life (Hébert et al., 2002).

Disease development is one of the principal causes of premature termination of postharvest shelf life of strawberries. Numerous studies have conclusively established a key role for constitutive and induced phenolic compounds in defense of plant tissues against pathogen attacks (Nicholson and Hammerschmidt, 1992; Prusky, 1996). Phenolic compounds, such as catechin, and the main constitutive unit of proanthocyanidins (PA), which are oligomers of flavan-3-ols, were associated to *Botrytis cinerea* resistance (Di Venere et al., 1998; Feucht et al., 1992). Hébert et al. (2002) evaluated in vitro the inhibition of grey mold growth of six strawberry cultivars and found that 'Seascape' PA extract gave the highest inhibition of mold radial growth (76.2%) and its fruit was also the most resistant to the appearance of mold during storage (22 d) with excellent shelf life. 'Harmonie' (Khanizadeh et al., 2005) 'Saint-Jean d'Orléans' (Khanizadeh, 2003b) and 'Orléans' (Khanizadeh et al., 2003), all being more resistant to diseases and some disease resistant advanced lines ('FIO9913-29', 'SJ8976-1', 'FIO9917-25', 'APF9335-26', 'FIO9923-7', and 'FIO996-2') were higher in hydroxycinnamic acids, benzoic acids, and flavonols than 'Kent' (Table 2). It seems that there is a possibility that low susceptibility of these cultivars to diseases might be due to their antioxidant activity and/or phenolic compounds as demonstrated previously on other crop species (Mayr et al., 1997; Wang et al., 1994). According to these authors, phenolics were the main compounds involved in the effective defense of plant tissues (i.e., mayhaws berries and apples) against field and postharvest infection or injuries and were significantly more active individually than in combination. It has been shown that benzoic acids have antibacterial, antifungal and antioxidant properties to prevent food spoilage and to enhance quality and shelf life (Baldwin et al., 1995; Khan et al., 1999). Lindhard Pedersen (2003) found that resistance to the diseases of five black currant (*Ribes nigrum* L.) cultivars was correlated with their high levels of hydroxycinnamic acid derivatives. Moreover, these acids can react with organic molecules such as amino acids to synthesize secondary metabolites that become highly toxic to the pathogen (Nicholson and Hammerschmidt, 1992).

In summary, our results show a significant variation in antioxidant capacity and total phenolic compound in selected strawberry genotypes and this investigation clearly shows the potential value of certain new cultivars and advanced lines and their possible use in breeding programs. Moreover, development of new strawberry fruit with higher antioxidant capacity may not only enhance resistance to diseases and increase shelf life but also stimulate greater interest in the nutraceutical and functional food aspects to strawberry consumption and potentially help to reduce risks of cancers and heart diseases (Galati et al., 2004; Halliwell, 1997; Liu, 2003; Maas et al., 1991).

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