Physical attributes and chemical composition of organic strawberry fruit (Fragaria x ananassa Duch, Cv. Albion) at six stages of ripening

José de Jesús Ornelas-Paz a,*, Elhadi M. Yahia b, Nidia Ramírez-Bustamante a, Jaime David Pérez-Martínez c, María del Pilar Escalante-Minakata d, Vrani Ibarra-Junquera d, Carlos Acosta-Muñiz a, Víctor Guerrero-Prieto a, Emilio Ochoa-Reyes a

a Centro de Investigación en Alimentación y Desarrollo A.C.–Unidad Cuauhtémoc, Av. Río Conchos S/N, Parque Industrial, C.P. 31570, Cd. Cuauhtémoc, Chihuahua, Mexico
b Facultad de Ciencias Químicas, Universidad Autónoma de San Luis Potosí, Manuel Nava No. 6, Zona Universitaria, C.P. 78210, San Luis Potosí, Mexico
c Facultad de Ciencias Naturales, Universidad Autónoma de Querétaro, Avenida de las Ciencias S/N, C.P. 76230, Juriquilla, Querétaro, Mexico
d Centro de Investigación en Alimentación y Desarrollo A.C.–Unidad Cuauhtémoc, Av. Río Conchos S/N, Parque Industrial, C.P. 31570, Cd. Cuauhtémoc, Chihuahua, Mexico

* Corresponding author. Tel.: +52 625 5812920x110; fax: +52 625 5812920. E-mail address: jornelas@ciad.mx (J. de J. Ornelas-Paz).

Article info
Article history:
Received 26 January 2011
Received in revised form 19 October 2012
Accepted 2 November 2012
Available online 10 November 2012

Keywords:
Antioxidants
Healthy fruit
Bioactive compounds
Quality
Ripening

Abstract
Organic strawberry fruits (Cv. ‘Albion’) were harvested at six different ripening stages and evaluated for physical and chemical parameters. Biometrical characteristics and moisture content did not change significantly during ripening. Total soluble solids, pH and colour development increased while titratable acidity and fruit firmness decreased 14.7% and 91%, respectively. Fructose, glucose, and sucrose followed similar tendencies. Final contents of these sugars were 2323.4, 1988.5, and 1578.4 mg/100 g, Citric, malic, and ascorbic acids followed a descending, irregular, and increasing tendency during ripening, respectively. Final contents of these acids were 822.8, 245.8, and 78.1 mg/100 g. Total anthocyanins content (TAC) increased during ripening, while the opposite was observed for total phenolic content (TPC). TAC and TPC in ripe fruit were 56.4 mg/100 g and 196 mg gallic acid equivalents (GAE)/100 g. Twenty eight phenolic compounds, mainly glycosides, were identified and quantified by HPLC-DAD–MS analysis. The concentration of these compounds was ripening dependent.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Quality of strawberry fruits depends mainly on their appearance (colour and biometrical characteristics), firmness, and chemical composition (Gunness, Kravchuk, Nottingham, D’Arcy, & Gidley, 2009). Values of these attributes determine crop value (Gunness, Kravchuk, Nottingham, D’Arcy, & Gidley, 2009). Quality attributes of strawberries are highly influenced by ripening. As non-climacteric fruit, strawberries must be harvested at full ripening stage since they do not develop quality attributes suitable for fresh consumption following detachment (Nunes, Brecht, Morais, & Sargent, 2006). However, ripening dynamics depends on cultivar type and cultivation mode, among other factors (Voca et al., 2009). Different fruit growing patterns have been reported for several strawberry cultivars (Perkins-Vezzie & Huber, 1987; Stutte & Darnell, 1987). Increasing, decreasing, and irregular tendencies have been observed for sugars and organic acids in fruit from several strawberry cultivars during ripening (Kafkas, Kosar, Paydas, Kafkas, & Baser, 2007; Montero et al., 1996; Ménager, Jost, & Aubert, 2004). Large differences in colour, total soluble solids,
and titratable acidity have been reported for ripe strawberry fruit from Mexican and American cultivars (Martínez-Bolaños et al., 2008). Cordenunsi, Oliveira do Nascimento, and Lajolo (2003) also found great variations in firmness and the content of anthocyanins, phenolic compounds, citric acid, and some sugars (sucrose, fructose and glucose) in ripe strawberries from several cultivars and concluded that cultivar type is the most important factor that is involved on the determination of the post-harvest quality and shelf-life. Similarly, cultivation mode alters ripening dynamics. Voca et al. (2009) found large differences in quality of strawberry fruit grown in plastic tunnel or on open field. Some studies have suggested that organically grown foods are richer in phenolic compounds than those produced by conventional agricultural practices (Asami, Hong, Barrett, & Mitchell, 2003). Organic strawberry cultivation is becoming popular world-wide since it increases safety and commercial value of this fruit. Quality of strawberry fruit also is strongly affected by geographical origin (Hakala, Lapvetelainen, Huopalahti, Kallio, & Tahvonen, 2003).

‘Albion’ strawberry cultivar was developed in USA and recently introduced to many countries, including Mexico, where is commercially cultivated under several climatic conditions and cultivation modes. Gunness, Kravchuk, Nottingham, D’Arcy, and Gidley (2009) recently studied some quality parameters (firmness, titratable acidity, total soluble solids, and volatile compounds) in ‘Albion’ strawberry at six stages of ripening. However, other quality parameters have not been determined in ‘Albion’ fruit during ripening, especially in fruit grown under organic cultivation. Literature regarding to this strawberry cultivar is scarce. The objective of the present study was determine several physical and chemical attributes of organic ‘Albion’ strawberries at six ripening stages.

2. Materials and methods

2.1. Plant material

The strawberry plants were grown on field under a plastic greenhouse in Chihuahua, Mexico. Temperature inside of greenhouse was controlled during fruiting stage, allowing day and night temperatures only into the range from 10 to 30 °C. Irrigation was applied each third day (17,280 L/ha/ctre). Strawberry cultivation was performed under organic conditions. Fruits were harvested at six different stages of ripening based on surface colour development, ranging from white to dark red (see Table 1 for ripening stage assignment). Each sample contained at least 180 fruits for each ripening stage. Fruits were washed with water, drained, and dried with paper towels. Fruit sepals were removed, discarding damaged fruits. Sub-samples of fruits were immediately evaluated for biometrical characteristics (weight, length, and major diameter), tristimulus colour, firmness, moisture content, titratable acidity, total soluble solids, pH, AA, and total phenolic compounds.

Table 1

<table>
<thead>
<tr>
<th>Ripening Stage</th>
<th>L*</th>
<th>C*</th>
<th>h*</th>
<th>Firmness (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White (RS1)</td>
<td>59.7 ± 0.3</td>
<td>28.5 ± 0.4</td>
<td>101.2 ± 0.7</td>
<td>42.4 ± 1.5</td>
</tr>
<tr>
<td>Turning (RS2)</td>
<td>61.7 ± 0.7</td>
<td>26.7 ± 0.7</td>
<td>88.3 ± 2.0</td>
<td>24.5 ± 1.0</td>
</tr>
<tr>
<td>Half-red (RS3)</td>
<td>49.6 ± 1.0</td>
<td>23.9 ± 0.9</td>
<td>54.2 ± 2.1</td>
<td>10.8 ± 0.5</td>
</tr>
<tr>
<td>Three-quarter red (RS4)</td>
<td>50.4 ± 1.8</td>
<td>31.7 ± 1.1</td>
<td>45.8 ± 2.6</td>
<td>9.0 ± 0.4</td>
</tr>
<tr>
<td>Bright red (RS5)</td>
<td>33.8 ± 0.4</td>
<td>34.2 ± 0.8</td>
<td>27.0 ± 0.7</td>
<td>6.0 ± 0.3</td>
</tr>
<tr>
<td>Dark-red (RS6)</td>
<td>35.2 ± 0.3</td>
<td>42.8 ± 0.7</td>
<td>18.2 ± 0.6</td>
<td>3.8 ± 0.2</td>
</tr>
</tbody>
</table>

Values represent the mean of several individual measurements (N = 6–45) ± the standard error. Values in the same column not connected by the same letter are significantly different (p < 0.05).

Sub-samples of strawberry fruits (whole or cut) were frozen and stored at −20 °C until total anthocyanins, sugars (fructose, glucose and sucrose), and other organic acids (citric and malic) analysis. The profile of individual phenolic compounds was also qualitatively and quantitatively determined in frozen strawberries.

2.2. Determination of biometrical characteristics, colour, total soluble solids, pH, titratable acidity, and moisture content

Biometrical characteristics (weight, length, and major diameter) were evaluated on 45 fruits. Weight (in g) was determined using an analytical balance while length and major diameter (in mm) were measured using a Vernier caliper. Next, fruits were evaluated for tristimulus colour. Surface colour was measured on two opposite sides of each one of the 45 fruits (equatorial area) using a Minolta colourimeter (Minolta, Co. Ltd., Osaka, Japan). L*, C*, and h* values were recorded.

After biometrical characterisation and tristimulus colour determination, strawberries were longitudinally cut in four identical portions. Strawberry portions were randomly distributed in 12 sub-samples. Six sub-samples were individually juiced, using a commercial juice extractor. Total soluble solids content (TSS) and pH were directly measured in the obtained juice using a Pal-1 hand refractometer (ATAGO, Co. Ltd., Osaka, Japan) and a pH/mV meter (Denver Instruments, Arvada, CO, USA), respectively. Remainder sub-samples (6) were individually processed to puree (using a kitchen blender), which was used for titratable acidity (TA) determination. Aliquots of puree (10 g) were homogenised in the presence of deionised water (30 mL) using an Ultra-turrax T18 basic homogeniser (Ika Works Inc., Wilmington, NC, USA). Volume of the mixture was adjusted to 100 mL with deionised water and then filtered. Next, the pH of the filtered extract was raised to 8.3 by adding 0.1 M NaOH. TA calculation was performed as reported by Gunness et al. (2009). TA was expressed as %. Sub-samples of strawberry puree that were used for TA also were employed for moisture content determination. Five grams of strawberry puree were placed in a Petri dish and dried at 70 °C under vacuum until constant weight. The % of moisture was determined gravimetrically.

2.3. Firmness evaluation

Firmness was determined on the equatorial region of 15 fruits, using a TA-XT2i texture analyzer (Stable Micro System Ltd.; Godalming, Surrey, England). This apparatus was dotted with an 8 mm diameter stainless steal striker pin, which punctured the fruits 10 mm at a rate of 10 mm/s. Two measurements were done on two opposite sides of each fruit, recording the maximum force (in Newton) that was needed to puncture the strawberry fruit.

2.4. Analysis of organic acids and sugars by HPLC

Forty strawberries (fresh) were cut in four identical portions, which were randomly distributed in 12 sub-samples. Six sub-samples were immediately used for AA determination while remainder samples were frozen and stored at −20 °C until analysis of citric acid, malic acid, sucrose, glucose, and fructose. In both cases, sub-samples were homogenised to puree in a kitchen blender. For AA analysis, puree aliquots (2 g) were homogenised in the presence of 4% metaphosphoric acid (15 mL). The mixture was centrifuged at 8425 g for 10 min at 5 °C. The extract was filtered through a polyethylene membrane of 0.45 μm of pore size (Millipore Corp., Bedford, MA, USA) and manually injected (20 μL) into the HPLC system (Varian Inc., Walnut Creek, CA, USA), which was composed by a ternary pump (Solvent Delivery System Model 9012), a UV/Vis detector (Model 9050) and a Refractive Index...
2.5. Determination of the total phenolic content

Fresh strawberries (20 fruits) were cut in four identical portions, which were randomly distributed in six sub-samples. Subsamples were individually homogenised to puree using a kitchen blender and immediately analysed for total phenolic content (TPC). Aliquots of pureed strawberries (5 g) were homogenised with 15 mL of 70% methanol (containing 5% of acetic acid) and then centrifuged as mentioned above for AA determination. The extract was recovered and diluted properly with 70% methanol (containing 5% of acetic acid). Aliquots (0.25 mL) of the extract were mixed with 1.25 mL of 10% Folin–Ciocalteau reagent and 1 mL of a sodium carbonate solution (75%, w/v). The mixture was incubated at 45 °C during 40 min. The absorbance of the solution was determined at λ = 750 nm using a 6505 Jenway UV/Vis spectrophotometer (Jenway Ltd., Essex, England). This absorbance always was into the range from 0.6 to 0.8. Gallic acid was used as a standard reference for quantitative purposes (three independent sets of dilutions). TPC was expressed as mg gallic acid equivalents per 100 g of fresh strawberry (mg GAE/100 g).

2.6. Determination of total anthocyanin content by the pH-differential method

Twenty strawberries (frozen) were cut in four identical portions, which were randomly distributed in six sub-samples. Subsamples were homogenised to puree using a kitchen blender and analysed for total anthocyanin content (TAC) as reported by Giusti and Wrolstad (2001) with some modifications. Briefly, aliquots of pureed strawberries (2 g) were homogenised with 15 mL of methanol (containing 1% of HCl) and then centrifuged as mentioned above for AA determination. The extract was recovered. An appropriate dilution factor for the extract at each ripening stage was calculated by diluting such extract with 0.025 M potassium chloride buffer (pH = 1) until the absorbance of the extract at λ = 508 nm (λ_{vis-max} of the sample) ranged from 0.6 to 0.8. According to this dilution factor, two aliquots of the strawberry extract were diluted with 0.025 M potassium chloride buffer (pH = 1) and 0.4 M sodium acetate buffer (pH = 4.5), respectively. These dilutions were equilibrated for 15 min at room temperature and their absorbance determined at λ = 500 nm and λ = 700 nm. Absorbance values were corrected using that of deionised water. TAC (mg/L) in the extract was calculated using the following equation: TAC = [(A) MW_{PG-3-g} (DF[1000])/ε], where A is the absorbance difference [A = (A_{500nmHCl} - A_{700nmHCl}) - (A_{500nmHCl} + A_{700nmHCl})]; MW_{PG-3-g} is the molecular weight of pelargonidin-3-glucoside (432.2 g/mol); DF is the dilution factor and ε is the molar extinction coefficient for pelargonidin-3-glucoside (ε = 17330). TAC was expressed in mg/100 g considering the amount of strawberry tissue subjected to anthocyanins analysis.

2.7. Identification and quantification of individual phenolic compounds by HPLC-DAD–MS

Frozen strawberries (40 fruits for each ripening stage) were homogenised to puree using a kitchen blender. Aliquots of pureed strawberries (5 g) were sequentially washed with 70% methanol (containing 5% of acetic acid) and methanol (containing 1% of HCl) until solids became colourless. A volume of 70 mL was required for each solvent. The extracts were properly diluted and automatically injected (20 μL) into an HP 1100 series HPLC system (Hewlett-Packard GmbH, Waldbronn, Germany) equipped with a diode array detector. Samples were monitored at λ = 280, 320, and 520 nm. The HPLC system was equipped with an X Terra C18 reversed phase column (4.6 × 250 mm) (Waters Corp., Milford, MA, USA). The column was operated at 25 °C. The mobile phase consisted of 0.1% formic acid in water (eluent A) and acetoni trile (eluent B) with the following gradient program: 98% A/2% B at 0 min, 0% A/100% B at 60 min, and 0% A/100% B at 70 min. The flow rate of the mobile phase was 0.5 mL/min. The mass spectra of phenolic compounds were obtained using the chromatographic system described above, coupled to a 6210 time-of-flight (TOF) mass spectrometer (Agilent Technologies Corp., Palo Alto, CA, USA) equipped with an electrospray ionisation source (ESI) and Mass Hunter manager software (A.02.01). The MS system was operated in negative ion mode. High-purity nitrogen (99.999%) was used as nebulising (40 psi) and drying gas (12 L/min). The electrospray voltage and nebuliser temperature were 3.0 kV and 350 °C, respectively. Other operating conditions for the MS system have been previously reported (Rivera-Pastrana, Yahia, & González-Aguilar, 2010). The phenolic compounds were identified in strawberry samples by analysing their chromatographic pattern, UV/Vis and MS spectra. These data were also compared with those of reference compounds, when available, or reported in the literature. Quantitative data were obtained by calibration curves constructed with pure compounds (apigenin, caffeic acid, catechin, cinnamic acid, ellagic acid, (−)-epicatechin, gallic acid, kaempferol, myricetin, naringenin, p-coumaric acid, pelargonidin, p-hydroxybenzoic acid, quer cetin, sinapic acid, ferulic acid, and vanillic acid) (Sigma–Al drich, St. Louis, MO, USA) with a minimum of five concentration levels. Derivatives and glycosides of phenolic compounds were quantified as their precursors or aglycones. The galloyl–HHDG–glucose and proanthocyanidins (dimer and trimer) were quantified as ellagic acid and (−)-epicatechin, respectively. The cyanidin–3-O-glucoside and peonidin–3-O-glucoside were quantified as pelargonidin.

2.8. Statistical analysis

Data were analysed in a completely randomised-design. Statistical significance of the difference between stages of ripening was determined using an ANOVA followed by the Tukey–Kramer post hoc test taking 0.05 as the significance limit. Data analysis was performed using JMP statistical software (SAS Institute Inc., Cary, NC, USA).
3. Results and discussion

3.1. Changes in physical attributes during ripening

3.1.1. Biometrical characteristics

Weight (13.0 ± 1.2–17.6 ± 1.6 g), major diameter (26.2 ± 1.1–29.5 ± 1.3 mm), and length (36.9 ± 1.4–38.8 ± 0.9 mm) of strawberries did not change statistically during ripening (data not shown). This observation was unexpected since growing and ripening can occur simultaneously in strawberry fruit (Perkins-Veazie & Huber, 1987). Abeles and Takeda (1990) found an increasing growing phase from white to red stages in ‘Tribute’ strawberries. Similar findings have been reported for ‘Pajaro’, ‘Chandler’, and ‘Selva’ strawberries (Ferreyra, Viña, Mugridge, & Chaves, 2007; Figueroa et al., 2008; Perkins-Veazie & Huber, 1987). Biometrical characteristics of ‘Albion’ fruit during ripening have not been reported up to now, especially under organic cultivation mode. Thus, the observed changes in biometrical characteristics could be distinctive for tested fruit, considering that the growing pattern of strawberries seems to be cultivar dependent (Perkins-Veazie & Huber, 1987; Stutte & Darnell, 1987). Weight of tested strawberries (13.17.6 g) was lower than that of ‘Albion’ (24 g) strawberries cultivated in Australia presumably under conventional conditions (Gunness et al., 2009). Weight of studied fruits was also lower than that of ‘Chandler’ (24.9 g, from Chile) and ‘Pajaro’ (11.1–20.3 g) strawberry fruit; similar to that of ‘Feri’ (15.3–16.8 g) strawberries and; higher than that of Turkish (10.1 g), ‘Selva’ (9.4–11.5 g), Finnish (8.4 g), ‘Chandler’ (4–5 g, from Spain), and ‘Tribute’ (7 g) strawberries (Abeles & Takeda, 1990; Doymaz, 2008; Ferreyra et al., 2007; Figueroa et al., 2008; Gunness et al., 2009; Karligad, Yildirim, & Turan, 2009; Montero et al., 1996; Perkins-Veazie & Huber, 1987). Major diameter of tested fruits (26.2–29.5 mm) did not develop sufficiently during ripening to meet the best size (>32 mm) according to Mexican Official Norm (NOM-062-ZOO-1999). Major diameter of tested ripe fruit (RS6) was lower than that of Turkish strawberries (49 mm) (Doymaz, 2008). Length of tested fruits (36.9–38.8 mm) was similar (37.3 mm) to that of Turkish strawberries (Doymaz, 2008). Length and major diameter of strawberry fruit are scarcely reported. In general, tested fruit showed good biometrical characteristics.

3.1.2. Tristimulus colour

Colour development increased during ripening. L* values followed a three stepped tendency (RS1–RS2, RS3–RS4 and RS5–RS6) (Table 1). Changes of L* in ripening strawberries depend on cultivar type. Nunes et al. (2006) demonstrated that the changes in L* values showed a two stepped tendency in ‘Oso Grande’ strawberries during ripening. However, other different tendencies for L* have also been reported (Nunes et al., 2006). In our study, C* values decreased slightly until RS3 and then they increased significantly during the rest of the ripening process (Table 1). Similar changes in C* values have been reported for ripening ‘Selva’ strawberries (Ferreyra et al., 2007). In general, L* and C* values of tested ripe fruit (RS6; L* = 35.2, C* = 42.8) were in the typical range (L* = 31.8–42.7, C* = 35.1–45.6) reported in literature for fruit from many strawberry cultivars (Hernández-Muñoz, Almenar, Del Valle, Velez, & Gavara, 2008; Pelayo, Ebeler, & Kader, 2003). Hue (h°) values in tested fruit diminished continuously during ripening (Table 1). Initial h° value was reduced 82% during ripening. Ferreyra et al. (2007) also reported a continuous decrease of h° in ripening strawberries during two harvesting seasons. Similar tendencies for h° have been reported in ripening fruit from other strawberry cultivars (Nunes et al., 2006). Interestingly, fruit at RS6 showed one of the most low h° values reported for strawberry fruit up to now (typical h° values in ripe strawberries range from ~26 to 49) (Hernández-Muñoz et al., 2008; Pelayo et al., 2003). This value (h° = 18.2) fell into the reddest region of the chromaticity diagram, suggesting that tested fruit was considerably rich in red pigments. Changes in h° values were clearly correlated to anthocyanins accumulation (r = −0.9).

3.1.3. Firmness

Fruit firmness decreased 91% during ripening process (Table 1). Dramatic decreases in firmness were observed during the first three ripening stages (RS1–RS3); however, the rate of firmness loss diminished considerably during following ripening stages. Similarly, Ménager et al. (2004) found that firmness of the fruit decreased from white to half-red and then appeared to hold steady from three-quarters to full and dark red. In our study, the red stages of ripening (RS5 and RS6) showed similar firmness. Nunes et al. (2006) also reported that the firmness of ‘Chandler’ and ‘Sweet Charlie’ strawberries harvested at full red stage did not change during storage, even though the fruit appeared to be riper. In general, firmness (3.8 N) of fully ripe tested fruit (RS6) was somewhat over the typical range (1.6–3 N) reported for ripe fruit from common strawberry cultivars, including ‘Albion’ fruit grown in Australia under conventional conditions (Gunness et al., 2009; Lara, García, & Vendrell, 2004; Nunes et al., 2006). This quality attribute confers advantage to tested fruit for commercialisation, showing increased mechanical resistance. Firmness also plays an important role on sensorial quality of ‘Albion’ fruit (Gunness et al., 2009). Changes in firmness were highly correlated with those of h°, TSS, TA and TSS/TA ratio (r = 0.94, −0.75, 0.96, and −0.80, respectively), which are commonly used as ripening indicators for strawberries.

3.2. Chemical changes during ripening

3.2.1. Total soluble solids, titratable acidity, pH, and moisture content

TSS increased continuously during ripening (Table 2), although some changes were not statistically significant. Similar tendencies have been reported for many strawberry cultivars during ripening (Azodanlou, Darbellay, Luisier, Villettas, & Amad, 2004; Ménager et al., 2004). TSS in tested ripe fruits (RS6; TSS = 9.0%) was into the range (TSS = 4.8–10.9%) reported in literature for ripe strawberries (Kafkas et al., 2007; Karligad et al., 2009). In contrast to TSS, titratable acidity (TA) tended to decrease during ripening process (Table 2). TA in fruit from many strawberry cultivars (‘Cigale’, ‘Carezza’, ‘Darselect’, ‘Marmolada’, and ‘Chandler’) also decreased continuously during ripening (Azodanlou et al., 2004; Ménager et al., 2004). In our study, fruit at RS3 and RS4 showed the same TA. Similar findings have also been observed by others. Nunes et al. (2006) found that colour-break, three-quarter, and full red coloured ‘Oso Grande’ strawberries presented similar TA. Three-quarter and full red coloured ‘Sweet Charlie’ fruit also showed similar TA (Nunes et al., 2006). TA in tested ripe fruit (RS6; TA = 0.7%) was similar to that reported for ripe strawberries (TA = 0.5–0.8%) (Azodanlou et al., 2004). The changes in TA and TSS were highly correlated each other (r = −0.88). The perceived sweetness of ripe ‘Albion’ fruit depends on TSS/TA ratio, tending to increase as TSS/TA ratio also increases (Gunness et al., 2009). In our study, TSS/TA ratio augmented gradually as ripening advanced (Table 2), agreeing with previous studies (Ménager et al., 2004). TSS/TA ratio in tested ripe fruit (RS6; TSS/TA = 12.9) was higher than that of Australian ‘Albion’ strawberries (TSS/TA = 9.9) cultivated under conventional conditions. This maximum value of TSS/TA is within the typical range reported (8.5–17) for ripe strawberries (Kafkas et al., 2007; Montero et al., 1996).

The pH also plays an important role on sensorial quality of ‘Albion’ strawberries, affecting the perception of sweetness as pH
increase (Guinness et al., 2009). In this work, pH tended to increase during ripening (Table 2), and their changes correlated well with those of TA (r = −0.9). Montero et al. (1996) found that the pH increased continuously in ‘Chadler’ strawberries during ripening. Similar findings have been reported for ‘Oso Grande’ and ‘Sweet Charly’ strawberries (Nunes et al., 2006). The pH of tested ripe fruit (RS6; pH = 3.8) was similar to that of ripe fruit (pH = 3.4–3.8) from many strawberry cultivars (‘Camarosa’, ‘Aromas’, ‘Diamante’, ‘Selva’, ‘Oso Grande’, ‘Dover’, ‘Campineiro’, ‘Mazi’, ‘Chandler’, and ‘Sweet Charly’), including ripe ‘Albion’ strawberries (pH = 3.5) grown in Australia (Cordenunsi et al., 2003; Guinness et al., 2009; Hernández-Muñoz et al., 2008; Nunes et al., 2006; Pelayo et al., 2003). However, pH of tested ripe strawberries (RS6) was considerably lower than that of ‘Toyonoka’ (4.2) strawberries (Cordenunsi et al., 2003) and higher than that of ‘Pajaro’ (3.16) strawberries (Lara et al., 2004).

The moisture content in tested fruit remained constant during ripening (Table 2). Similarly, moisture content in ‘Yolo’ strawberry varieties remained unchanged (90%) during ripening process (Koh & Melton, 2002). Moisture content in tested ‘Albion’ strawberries (91.9–93.2%) was within the typical range reported (87.5–94.7%) in the literature for strawberry fruit (Tulipani et al., 2008).

### 3.2.2. Individual and total sugars and acids

Changes in fructose, glucose, and sucrose followed a tendency composed by two increasing-decreasing periods, showing maximum values at RS2 and RS5 (Fig. 1A). This tendency was distinctive for tested fruit. Changes in individual sugars are cultivar dependent. Ménager et al. (2004) demonstrated that sucrose, glucose, and fructose accumulated gradually in ‘Cigaline’ strawberries as ripening advanced. In contrast, Kafkas et al. (2007) found that the sucrose content in fruit from one strawberry genotype (Hybrid 11) decreased continuously during ripening while the content of sucrose, glucose, and fructose decreased from the pink to red stage of ripening in fruit from other strawberry genotypes (‘Camarosa’ and Hybrids 6, 8, and 12). Sturm, Koron, and Stampar (2003) also demonstrated that the content of sucrose in fruit from several strawberry cultivars decreased during ripening. Montero et al. (1996) reported that the content of glucose and fructose in ripening ‘Chandler’ fruit increased continuously during 35 days after fruit set, showing a decrease after 42 days from fruit set while sucrose content increased continuously until 21–28 days from fruit set and then decreased gradually during the rest of the ripening process. On the other hand, the content of sucrose, glucose, and fructose in ‘Selva’ strawberries after reaching 25–50% of red colour changed irregularly during the following stages of ripening (Ferrerya et al., 2007). The content of fructose and glucose (2322.4 and 1988.5 mg/100 g) in tested ripe fruit (RS6) was higher than that of ‘Aromas’ (1840 and 1500 mg/100 g), ‘Diamante’ (2050 and 1690 mg/100 g), ‘Selva’ (1950 and 1550 mg/100 g), ‘Dover’ (~1500 and ~1225 mg/100 g), ‘Campineiro’ (~1700 and ~1300 mg/100 g), ‘Mazi’ (~1900 and ~1700 mg/100 g), ‘Oso Grande’ (1940 and 1777 mg/100 g), and ‘Camposa’ (2183 and 1313 mg/100 g) strawberries but lower than that of ‘Cigaline’ (2960–3260 and 2820–2970 mg/100 g) and ‘Osmanli’ (4240 and 2660 mg/100 g) strawberries (Cordenunsi et al., 2003; Kafkas et al., 2007; Pérez, Olías, Espada, Olías, & Sanz, 1997). Sucrose content (1578 mg/100 g) in ripe fruit (RS6) was in the typical range reported in the literature (515–2275 mg/100 g) (Kafkas et al., 2007; Pérez et al., 1997), although sucrose might not be detected in some strawberry fruit (Montero et al., 1996). Interestingly, tested strawberries at RS6 contained two or three times more sucrose than ripe fruit from ‘Aromas’ (780 mg/100 g) and ‘Oso Grande’ (515 mg/100 g) cultivars, which are considered as rich in sucrose (Pelayo et al., 2003; Pérez et al., 1997).

The studied organic acids showed different behavior during strawberry ripening (Fig. 1B). High correlation coefficients were observed between the content of citric acid or AA and TA (r = 0.86 and −0.95) or pH (r = −0.92 and 0.96). The content of malic acid did not correlate with TA or pH. Citric acid content decreased continuously along ripening process, as reported for ‘Cigaline’, ‘Pegasus’, ‘Cortina’, ‘Evita’, ‘Mohawk’, and two Turkish strawberry genotypes (Hybrids 3 and 8) (Kafkas et al., 2007; Ménager et al., 2004; Sturm et al., 2003). However, continuous increases and other tendencies for citric acid content have also been reported for fruit from other strawberry cultivars during ripening (Kafkas et al., 2007; Montero et al., 1996). Citric acid content (822.8 mg/100 g) in ripe fruit (RS6) was considerably higher than that of ‘Aromas’ (350 mg/100 g), ‘Diamante’ (680 mg/100 g), ‘Selva’ (720 mg/100 g), ‘Dover’ (~700 mg/100 g), ‘Toyonoka’ (~600 mg/100 g), ‘Campineiro’ (~700 mg/100 g), ‘Mazi’ (~600 mg/100 g), ‘Oso Grande’ (321 mg/100 g), ‘Cigaline’ (520–550 mg/100 g), and ‘Elsanta’ (740 mg/100 g) strawberries (Cordenunsi et al., 2003; Kafkas et al., 2007; Ménager et al., 2004; Pelayo et al., 2003; Pérez et al., 1997). ‘Korona’ (850 mg/100 g), ‘Camposa’ (1521 mg/100 g), and ‘Osmanli’ (1885 mg/100 g) strawberries contain more citric acid than tested ripe fruit (Kafkas et al., 2007; Keutgen & Pawelzik, 2007).

Changes in malic acid content did not follow a clear tendency during ripening. Similar findings have been reported for fruit from ‘Cigaline’ and several Turkish strawberry genotypes (Kafkas et al., 2007; Ménager et al., 2004). The content of malic acid in tested ripe fruit (245.8 mg/100 g) was similar to that reported (200–280 mg/100 g) for fruit from many strawberry cultivars, including ‘Aromas’, ‘Diamante’, ‘Selva’, ‘Korona’, ‘Elsanta’, and ‘Osmanli’ cultivars (Kafkas et al., 2007; Keutgen & Pawelzik, 2007; Pelayo et al., 2003). However, malic acid content in tested ripe fruit was considerably higher and lower than that reported for ripe ‘Oso Grange’ (111 mg/100 g) and ‘Camposa’ (539 mg/100 g) strawberry fruit, respectively (Kafkas et al., 2007; Pérez et al., 1997).

AA increased continuously during ripening process. Similarly, Kafkas et al. (2007) demonstrated that the AA content increased in fruit from ten strawberry cultivars during ripening. Montero et al. (1996) also observed that the AA content increased in ‘Chadler’ strawberries during ripening. The AA content (78.1 mg/100 g) in tested ripe fruit (RS6) was within the typical range reported (19–110 mg/100 g) for strawberries and was considerably high, being only slightly lower than that reported for ‘Campineiro’ (80 mg/100 g), ‘Dover’ (~80 mg/100 g), ‘Camarosa’ (84 mg/100 g), and ‘Selva’ (100–110 mg/100 g) strawberries (Pérez et al., 1997; Cordenunsi, Genovese, Oliveira do Nascimento, Hasmimotto, dos Santos & Lajolo, 2005; Ferrerya et al., 2007; Kafkas et al., 2007; Nunes et al., 2006). Therefore, tested strawberries can be considered as rich in vitamin C, having potentially great beneficial effects on human nutrition and health. Vitamin C prevents allergies, reduces the levels of circulating proinflammatory cytokines, modulates gene expression and cell cycle progression, etc.
prevents some forms of cancer and neurological (Alzheimer, Parkinson, Huntington, and cerebral ischemia) and cardiovascular diseases (Davey et al., 2000; Harrison & May, 2009). AA is involved in neural maturation, neuronal transmission, learning/memory, and locomotor activity (Harrison & May, 2009).

Values of total sugars (sum of fructose, glucose, and sucrose contents), total organic acids (sum of the contents of citric, malic, and ascorbic acids) and total sugars/total organic acids ratio are shown in Fig. 1C. The changes in total sugars content did not correlate with TSS while total acids content and TA correlated each
other ($r = 0.85$). Kafkas et al. (2007) did not find statistical correlation between TSS and total sugars in ripening strawberries from several cultivars. However, they (Kafkas et al., 2007) did not find correlation between the changes of total acids content and TA. In our study TSS/TA and total sugars/total organic acids ratios followed different tendencies during ripening, as reported by Montero et al. (1996) for ‘Chandler’ strawberries. No statistical correlation was found between these two ratios.

### 3.2.3. Total and individual phenolic compounds

TPC tended to decrease during ripening (Table 3), agreeing with other studies carried out in fruit from other strawberry cultivars. Ferreyra et al. (2007) demonstrated that TPC decreases continuously in ‘Selva’ strawberries during ripening. In ‘Chandler’ strawberries, a sharp decrease in TPC was observed during the first stages of fruit development until day 21 after fruit set, and from the day 28 on there was a slight increase in the concentration of these components due to an accumulation of anthocyanins (Montero et al., 1996). Similar changes also have been observed in fruit from other strawberry cultivars (‘Sweet Charlie’ and ‘Oso Grande’) during ripening (Nunes et al., 2006). Asami et al. (2003) reported that organically and sustainably grown foods are richer in total phenolics than those produced by conventional agricultural practices. Consistently, TPC (195.6 mg GAE/100 g) in tested ripe fruit (RS6) was considerably higher than that reported for fruit from many strawberry cultivars, including fruit from ‘Aromas’ (144 mg/100 g), ‘Diamante’ (136 mg/100 g), ‘Selva’ (136 mg/100 g), ‘Chandler’ (~120 mg/100 g), ‘Oso Grande’ (~97 mg/100 g), and ‘Sweet Charlie’ (~97 mg/100 g) cultivars grown under conventional conditions (Nunes et al., 2006; Pelayo et al., 2003). Such value in tested ripe fruit was only lower than that of fruit (299-324 mg/100 g) from some Brazilian cultivars (‘Dover’, ‘Campineiro’, and ‘Oso Grande’) (Cordenunsi et al., 2005).

TAC increased continuously during ripening (Table 3). Similar changes have been reported in ripening fruit from many strawberry cultivars (Ferreyra et al., 2007; Montero et al., 1996; Nunes et al., 2006). TAC was positively correlated to $h^*$ values ($r = -0.9$). Anthocyanins are the pigments responsible for the typical colour of strawberry fruit; however, the colour of anthocyanins depends on their hydroxylation pattern of the B-ring. TAC in tested ripe fruit (56.4 mg/100 g) was very close to the upper limit of the typical range (18–60 mg/100 g) reported in the literature for strawberries, being only lower than that of ‘Oso Grande’ (~60 mg/100 g) strawberries grow in Brazil (Cordenunsi et al., 2003).

Twenty eight phenolic compounds were identified by HPLC-DAD–MS analysis (Table 4), including phenolic acids derivatives (peaks 1, 3, 7, 9, 11, 12, 22, and 24), flavanols (peaks 15), flavanones (peak 21), flavones (peaks 5 and 28), flavonols (peaks 4, 18, 20, 25, 26, and 27), coumarins (peak 8), ellagitanins (peak 16), proanthocyanidins (peaks 2 and 14), and anthocyanins (peaks 6, 10, 13, 17, 19, and 23). In general, the phenolic compounds that were detected in tested fruits have been also previously identified in fruit from several strawberry cultivars (Aaby, Ekeberg, & Skrede, 2007; Herrera & Luque de Castro, 2004; Kajdzanowska, Gajmowski, & Stefowa, 2010; Pinto, Laljo, & Genovese, 2008; Silva et al., 2007; Zheng, Wang, Wang, & Zheng, 2007). Almost all of the phenolic compounds were glycosylated, agreeing with literature (Aaby et al., 2007; Kajdzanowska et al., 2010). Only two compounds (catechin and naringenin; peaks 15 and 21) were detected in free/unglycosylated form. Several studies have demonstrated that glycosides of catechin, naringenin, and phenolic acids are rare in the nature, mainly in strawberries (Aaby et al., 2007; Kajdzanowska et al., 2010; Silva et al., 2007; Zheng et al., 2007). The content of individual phenolic compounds is shown in Table 5. The content of total phenolic acids derivatives (sum of the contents of individual phenolic acids derivatives) was continuously increased, from 93.2 to 163.6 mg/100 g, during the first 4 ripening stages and then descended up to 82.7 mg/100 g in fruit at RS6. The most abundant phenolic acids were cinnamic acid-3-O-acetyl-glucoside, ferulic acid hexose derivative, and vanillic acid-3-O-malonyl-glucoside (Table 5), representing 11.5–50.3%, 14.0–42.1%, and 2.4–47.4% of total phenolic acids. These compounds along with caffeoylhexose (all of them being phenolic acids derivatives) were detected in fruit at the six ripening stages. The concentration of these phenolic acids derivatives had not been reported previously in strawberry fruits.

The initial content of total flavonoids (sum of the contents of individual flavonoids) gradually diminished (73.7%) during the ripening process, from 246.5 to 64.8 mg/100 g. The content of individual flavanols also diminished gradually during the ripening (Table 5). The kaempferol derivatives (kaempferol-3-O-glucose, kaempferol-3-O-coumaroyl glucoside, kaempferol hexose, and kaempferol-3-O-acetyl-glucoside) were the most abundant flavonols, representing 60.4–86.6% of total flavonol content. This flavonol, as kaempferol derivatives, also was the most abundant flavonol in fruit of other strawberry cultivars (Kajdzanowska et al., 2010). The content of kaempferol-3-O-glucose in fruits at the RS6 was considerably higher than that of fully ripe ‘Allstar’ strawberries (Zheng et al., 2007). The content of quercetin-3-O-glucose in fruits at RS6 (15 mg/100 g) was similar to those reported previously (8.8–16 mg/100 g) for fully ripe strawberries from other cultivars (Zheng et al., 2007). The myricetin derivatives were only observed in some ripening stages at low concentration (6.4–35.2 mg/100 g). The concentration of this flavonol derivative had not been reported previously in strawberries.

The concentration of individual flavanols (catechin) and flavones (apigenin-pentoside and apigenin-6-C-hexoside-8-C-pentoside) was from low to moderate (35.1–229.3 and 4.0–131.2 mg/100 g, respectively) (Table 5). However, the level of catechin in fruits at RS6 was higher than those reported for ripe fruit of several strawberry cultivars (0-5.7 mg/100 g) (Pinto et al., 2008). Low levels of the flavanone naringenin have been reported for strawberries (Herrera & Luque de Castro, 2004). In our study, the initial content (RS1) of naringenin was high (157.9 mg/100 g) but gradually diminished up to 2.5 mg/100 g in fruit at RS6. The coumarins (coumarin-3-O-acetyl-glucoside) and proanthocyanidins (dimer and trimer) were detected at low levels only in some ripening stages. The levels of the ellagitanin galloyl-HHDP-glucose were considerably low and constant during the first five ripening stages, but increased abruptly in fruits at RS6 (235.5 mg/100 g). These compounds have been previously identified in strawberries but their levels had not been determined (Kajdzanowska et al., 2010).

Individual anthocyanins were not detected in fruits at RS1 while strawberries at RS2 only contained trace amounts of pelargonidin-3-O-rutinoside. Several anthocyanins were detected in fruits at RS3–RS6. The contents of pelargonidin-3-O-rutinoside diminished gradually

---

**Table 3**

<table>
<thead>
<tr>
<th>Ripening stage</th>
<th>Total phenolics content (mg GAE/100 g)</th>
<th>Total anthocyanins (mg/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS1</td>
<td>326.0 ± 4.9*</td>
<td>ND*</td>
</tr>
<tr>
<td>RS2</td>
<td>245.5 ± 3.8*</td>
<td>0.9 ± 0.1*</td>
</tr>
<tr>
<td>RS3</td>
<td>226.2 ± 2.0*</td>
<td>4.3 ± 0.2*</td>
</tr>
<tr>
<td>RS4</td>
<td>209.7 ± 2.1*</td>
<td>16.1 ± 0.2*</td>
</tr>
<tr>
<td>RS5</td>
<td>208.4 ± 2.7*</td>
<td>34.4 ± 1.0*</td>
</tr>
<tr>
<td>RS6</td>
<td>195.6 ± 4.0*</td>
<td>56.4 ± 3.0*</td>
</tr>
</tbody>
</table>

Values represent the mean of several individual measurements ($N = 6$) ± the standard error. Values in the same column not connected by the same letter are significantly different ($p < 0.05$). 

* ND, not detected.

---
during the ripening while those of pelargonidin-3-O-glucoside increased (Table 5). The contents of pelargonidin-3-O-glucoside and pelargonidin-3-O-rutinoside in fully ripe strawberries were 39.0 and 12.6 mg/100 g, respectively. These pigments have been regarded as the major anthocyanin pigments in strawberries, being found at levels of 10.7–46.8 and 1.3–5.5 mg/100 g, in fully

Table 4
UV/Vis data, MS data, and tentative identification of individual phenolic compounds of strawberry fruit at six stages of ripening.

<table>
<thead>
<tr>
<th>Peak</th>
<th>RT (min)</th>
<th>)&lt;sub&gt;max&lt;/sub&gt; (nm)</th>
<th>m/z (relative abundance, %)</th>
<th>Tentative identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.1</td>
<td>242, 338, 328</td>
<td>161.0165 (19.3), 179.0145 (17.9), 341.0114 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Caffeoylhexose</td>
</tr>
<tr>
<td>2</td>
<td>22.9</td>
<td>284</td>
<td>289.0197 (8.6), 577.0168 (7.2), 865.0219 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Proanthocyanidin trimer</td>
</tr>
<tr>
<td>3</td>
<td>23.1</td>
<td>316</td>
<td>137.0588 (42.1), 299.0900 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>p-Hydroxybenzoic-3-glucoside</td>
</tr>
<tr>
<td>4</td>
<td>25.4</td>
<td>210, 282</td>
<td>315.0151 (7.9), 479.0417 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Myricitin-3-O-glucoside</td>
</tr>
<tr>
<td>5</td>
<td>27.3</td>
<td>338</td>
<td>269.0482 (21.2), 298.8108 (7.2), 356.9008 (5.7), 401.0115 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Apigenin-pentoside</td>
</tr>
<tr>
<td>6</td>
<td>28.2</td>
<td>502</td>
<td>518.8464 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pelargonidin-3-O-malonyl-glucoside</td>
</tr>
<tr>
<td>7</td>
<td>28.6</td>
<td>264, 296</td>
<td>174.0692 (17.26), 298.0110 (16.84), 415.0180 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Vanillic acid-3-O-malonyl-glucoside</td>
</tr>
<tr>
<td>8</td>
<td>28.9</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>349.0170 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Coumarin-3-O-acetyl-glucoside</td>
</tr>
<tr>
<td>9</td>
<td>30.1</td>
<td>270, 250, 274</td>
<td>102.9058 (41.4), 174.0540 (19.8), 351.0117 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Cinnamic acid-3-O-acetyl-glucoside</td>
</tr>
<tr>
<td>10</td>
<td>30.2</td>
<td>520</td>
<td>432.0322 (3.0), 145.0506 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Pelargonidin-3-O-glucoside</td>
</tr>
<tr>
<td>11</td>
<td>30.4</td>
<td>316</td>
<td>145.0149 (100.0), 163.0147 (5.5), 325.0134 (20.5)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>p-Coumaroylhexose</td>
</tr>
<tr>
<td>12</td>
<td>31.0</td>
<td>244, 326, 194</td>
<td>269.0119 (29.5), 289.0110 (16.84), 411.0125 (32.2), 449.0128 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Apigenin-pentoside</td>
</tr>
<tr>
<td>13</td>
<td>31.1</td>
<td>280, 516</td>
<td>285.0182 (12.7), 287.0168 (20.2), 448.8218 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Cyanidin-3-O-glucoside</td>
</tr>
<tr>
<td>14</td>
<td>31.9</td>
<td>238, 296, 318, 508</td>
<td>289.0197 (22.0), 407.0171 (11.3), 425.0113 (53.6), 577.0192 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Proanthocyanidin dimer</td>
</tr>
<tr>
<td>15</td>
<td>32.3</td>
<td>250, 284</td>
<td>136.9588 (30.6), 244.9544 (35.8), 289.0193 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catechin</td>
</tr>
<tr>
<td>16</td>
<td>33.2</td>
<td>232</td>
<td>301.0151 (23.1), 463.0191 (57.1), 633.0160 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Galloyl-HHDP-glucose</td>
</tr>
<tr>
<td>17</td>
<td>35.0</td>
<td>279, 517</td>
<td>112.9278 (19.4), 136.9588 (8.9), 174.0504 (9.0), 426.0569 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Peonidin-3-O-glucoside</td>
</tr>
<tr>
<td>18</td>
<td>36.8</td>
<td>258, 374</td>
<td>151.0532 (11.6), 174.0540 (23.8), 289.0117 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Quercetin-3-O-glucoside</td>
</tr>
<tr>
<td>19</td>
<td>40.1</td>
<td>272, 516</td>
<td>271.0877 (11.1), 301.0151 (23.1), 463.0161 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Galloyl-HHDP-glucose</td>
</tr>
<tr>
<td>20</td>
<td>40.8</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>349.0170 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Coumarin-3-O-acetyl-glucoside</td>
</tr>
<tr>
<td>21</td>
<td>41.7</td>
<td>250, 284</td>
<td>136.9588 (30.6), 244.9544 (35.8), 289.0193 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catechin</td>
</tr>
<tr>
<td>22</td>
<td>43.1</td>
<td>266, 348</td>
<td>301.0151 (23.1), 463.0191 (57.1), 633.0160 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Galloyl-HHDP-glucose</td>
</tr>
<tr>
<td>23</td>
<td>45.6</td>
<td>285</td>
<td>136.9588 (30.6), 244.9544 (35.8), 289.0193 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catechin</td>
</tr>
<tr>
<td>24</td>
<td>45.8</td>
<td>250, 284</td>
<td>136.9588 (30.6), 244.9544 (35.8), 289.0193 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catechin</td>
</tr>
<tr>
<td>25</td>
<td>45.9</td>
<td>250, 284</td>
<td>136.9588 (30.6), 244.9544 (35.8), 289.0193 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catechin</td>
</tr>
<tr>
<td>26</td>
<td>45.9</td>
<td>250, 284</td>
<td>136.9588 (30.6), 244.9544 (35.8), 289.0193 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catechin</td>
</tr>
<tr>
<td>27</td>
<td>45.9</td>
<td>250, 284</td>
<td>136.9588 (30.6), 244.9544 (35.8), 289.0193 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catechin</td>
</tr>
<tr>
<td>28</td>
<td>45.9</td>
<td>250, 284</td>
<td>136.9588 (30.6), 244.9544 (35.8), 289.0193 (100.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catechin</td>
</tr>
</tbody>
</table>

<sup>a</sup> ND, not detected.  
<sup>b</sup> Molecular ion.

During the ripening while those of pelargonidin-3-O-glucoside increased (Table 5). The contents of pelargonidin-3-O-glucoside and pelargonidin-3-O-rutinoside in fully ripe strawberries were 39.0 and 12.6 mg/100 g, respectively. These pigments have been regarded as the major anthocyanin pigments in strawberries, being found at levels of 10.7–46.8 and 1.3–5.5 mg/100 g, in fully.
ripe fruit of the most common strawberry cultivars (Silva et al., 2007; Zheng et al., 2007). The levels of cyanidin-3-O-glucoside were inside the range typically reported in the literature (1.1–4.1 mg/100 g) for strawberries (Silva et al., 2007). Silva et al. (2007) demonstrated that glucose and rutinose were the usual substituting sugars of anthocyanins. Low/trace levels of peonidin-3-O-glucoside and 5-pyranopelargonidin-3-O-glucoside were detected in tested strawberries only at some ripening stages (Table 5).

In general, the concentrations of total phenolic compounds as determined by the Folin–Ciocalteau's method were considerably lower than those obtained by the sum of the individual content of phenolic compounds. The limitations of the Folin–Ciocalteau assay have been widely described in the literature, including the interference of non-phenolic compounds and the underestimation/overestimation by differences in the λmax of individual phenolic compounds. However, this method is highly used for the determination of the TPC, allowing the quick comparison between samples (Ferreira et al., 2007). Interestingly, the TAC obtained by the pH differential method was slightly lower than that generated by the sum of the individual content of anthocyanins. This work demonstrates that ‘Albion’ strawberries are a good source of phenolic compounds, which gives importance to this strawberry cultivar on human health since phenolic compounds are potent antioxidants. Many studies have demonstrated protective roles of pheno-lic compounds against coronary heart disease, stroke, and some forms of cancer. These protective effects of phenolic compounds are attributed to their antiradical and signaling activities in the cells (Parr & Bolwell, 2000). The work also demonstrated that tested fruits are rich in anthocyanins. These consumption of these compounds reduces the incidence of cardiovascular diseases and some forms of cancer, prevent AA oxidation, protect macromolecules (i.e. DNA) against free radicals and inhibit activity of oxidative enzymes (Silva et al., 2007).

4. Conclusions

Fully ripe ‘Albión’ strawberries showed a markedly high firmness and presented a good appearance (colour and biometrical characteristics) under organic cultivation mode. These quality attributes make them suitable for commercialisation. Tested fruits were rich in sugars and acids, two chemical components that determine the sensorial quality of this fruit. According to literature, tested fruit presented a considerably high content of anthocy-anins and a moderate to high content of AA and total phenolic compounds, giving nutritional and health relevance to this fruit. Most of quality attributes of tested fruit were higher than those reported for strawberries commonly found in the market.

Acknowledgement

Authors thank Francisco Javier Esparza and Dulce María Rivera-Pastrana for their technical assistance. The authors are members of the research group on “Pigmentos Naturales (Enfasis en Carotenoides).”

References


