Screening on susceptibility to browning of organically grown apples for fresh-cut processing

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Abstract. The susceptibility to browning of seven cultivars of organically grown apples coming from three Italian regions and harvested at commercial maturity was investigated before long term storage. The flesh colour (L*, a*, b*, Browning Index -BI-, ∆L*, ∆BI) modifications were measured during a two hour period of air exposure, so evaluating the suitability to fresh-cut processing. After 120 min, ‘Golden Delicious’, ‘Golden Orange’ and ‘Pink Lady’ kept the highest L* values (80.54÷79.05), with no or very low percentage of severe browning, while ‘Renetta’ and ‘Gala’ from Pinerolo showed the highest value of BI (46.64÷41.66) coupled with a percentage of severe browning greater than 50%. Results indicated ‘Golden Delicious’, ‘Golden Orange’ and ‘Pink Lady’ as the more suitable cultivars for fresh-cut processing, and ‘Renetta’ and ‘Braeburn’ the least.
Riassunto. In questo lavoro è stata valutata la suscettibilità all’imbrunimento di sette cultivars di mele coltivate secondo il disciplinare di agricoltura biologica, provenienti da tre località d’Italia, raccolte a maturità commerciale e prima della conservazione. Sono state misurate le modificazioni del colore della polpa tramite i parametri di riflettanza \( L^* \), \( a^* \), \( b^* \) e l’indice di imbrunimento durante due ore di esposizione all’aria al fine di valutare l’idoneità dei frutti ad essere trasformati in prodotti pronti per il consumo (IV gamma). Dopo 120 min ‘Golden Delicious’, ‘Golden Orange’ e ‘Pink Lady’ hanno raggiunto i valori più elevati di \( L^* \) (80.54÷79.05), le cultivar ‘Renetta’, e la ‘Gala’ proveniente da Pinerolo i valori più elevati di indice di imbrunimento (46.64÷41.66), la cultivar ‘Renetta’ e ‘Gala’ proveniente da Pinerolo un’alta (≥50%) percentuale di superficie imbrunita in maniera intensa. ‘Golden Delicious’, ‘Golden Orange’ e ‘Pink Lady’ hanno dato i risultati migliori, mentre ‘Renetta’ e ‘Braeburn’ sono risultate essere le cultivar meno idonee alla trasformazione in prodotti di IV gamma.

Key words: fresh-cut products, susceptibility to browning, organically grown apples

Parole chiave: prodotti pronti per il consumo, suscettibilità all’imbrunimento, mele da agricoltura biologica

Introduction

In the last few years there has been an increase in demand of organically grown products. It is important to satisfy the consumer demand not only for fresh, but also for processed organically grown products. In particular, minimally processed fruits and vegetables could represent an expanding market; among them, ready-to-eat apples, also called “fresh-cut” apples, are much appreciated. Many studies have been carried out to obtain high quality
products (Bolin & Huxoll, 1989; Kim: et al., 1993; Senesi ,1993; Senesi . & Pastine ., 1996; Senesi et al.,1996).

Fresh-cut fruits include all the products that, after cleaning, peeling and cutting, are packed, cooled and sold. These products are pieces (segments, slices, cubes) of fruits that maintain their metabolic activity during storage. As for fresh-cut apples, the physical damage caused by processing could induce a deterioration of quality, especially related to colour (browning) and texture (softening), as a result of the activity of endogenous enzymes, the enhanced respiration and senescence (Klein, 1987), leading to a reduction of the shelf-life of the product.

Recently several efforts have been made to improve “fresh-cut” apples quality parameters. The effects of some compounds and technological treatments have been studied, such as apple-puree based edible films (McHugh & Senesi , 2000; Senesi & Bignardi , 2000) and other different edible coatings (Perez-Gago et al., 2005; Perez-Gago et al., 2006; Rojas-Grau et al., 2007), the use of filling liquid based on either isotonic or ipertonic fruit juice containing ascorbic acid, citric acid and calcium chloride (Senesi & De Regibus, 2002), the applications of 1-methylcyclopropene (Vasantha Rupasinghe et al., 2005), vitamin E (Zhao . et al., 2005), honey in combination with vacuum impregnation (Jeon & Zhao , 2005), peroxyacetic acid or acidic electrolyzed water or chlorine as sanitizers followed by calcium ascorbate treatment (Wang et al., 2007).

In order to widen the sort of tastes for fresh-cut apples, so as to satisfy the increasing demand of consumers for healthy and tasty fresh fruit products, it has arisen the necessity of studying the behaviour of diverse apple cultivars following fresh-cut processing, focussing on their susceptibility to browning.

Susceptibility to browning is an important parameter to be considered for the evaluation of the suitability of apples to fresh-cut processing. The mechanism of enzymatic browning in
Apples has been well described in literature (Nadudvari-Markus & Vamos-Vigyazo, 1984; Nicolas et al., 1994; Sapers & Douglas 1987; Vamos-Vigyazo, 1981; Walker & Wilson, 1975) and it is in relation with the different content and composition in polyphenolic compounds and with the various polyphenoloxidase (PPO) activities found in diverse cultivars; all these factors could induce differences in browning susceptibility from one cultivar to another (Amiot et al., 1992). Other factors, such as growing protocols and locality, harvest date, stage of ripeness and storage (Soliva Fortuny et al., 2002) affect polyphenolic composition and PPO activity, and so, the browning susceptibility during shelf-life. The extent of enzymatic browning has been studied so far only on apple cultivars obtained from local markets (Kuczinsky et al., 1992; Mastrocola et al., 1990; Sapers & Douglas, 1987), whose growing protocols were not specified and considered. Therefore, this work has been set up with the aim of testing the susceptibility to browning of different apple cultivars coming from different localities, cultivated according to the same protocol (certified organically grown fruit). For this purpose and in order to have representative fruit samples, seven apple cultivars from three localities were tested in a preliminary screening for the susceptibility to browning by monitoring flesh colour modifications during a two hour period of air exposure.

**Materials and Methods**

Apples of seven cultivars from organically grown orchards and coming from three different areas of Northern Italy were picked on September 2004 in correspondence of the commercial harvest maturity. ‘Golden Delicious’ and ‘Gala’ apples came from the experimental orchards of the Agricultural Research Centre in Laimburg (Trentino Alto Adige, Italy), and from commercial orchards located in Val Grana and Pinerolo (Piemonte, Italy); ‘Renetta’ fruits were picked from commercial orchard located in Pinerolo e Val Grana, while ‘Pink Lady’, ‘Braeburn’ and ‘Granny Smith’ cultivars were obtained from the Agricultural Research
Centre in Laimburg and ‘Golden Orange’ variety from a commercial orchard located in Pinerolo.

All the cultivars from all the localities were cultivated according to the CEE Regulation n. 2092/91 (Gazzetta Ufficiale della Comunità Europea n. L198, 22 July 1991) and following modifications, and the Legislative Decree n. 220/95 (Gazzetta Ufficiale della Repubblica Italiana, n 129, 17 March 1995) and following modifications, concerning the organically grown fruits and vegetables. On arrival at CRA-IAA, fruits were kept in air at 2±1 °C and 95% RH until flesh colour measurements, which were carried out on the fruit cut surface throughout a 2 h air exposure time.

According to Sapers and Douglas (1987), one hour before starting the test, three apples per cultivar and location were removed from the warehouse and kept at room temperature (20±1°C). Then each fruit was cut in half, vertically from the stalk downwards, with a sharp knife in order to obtain a smooth surface for colour measurements (Kuczinsky et al., 1992). On each half apple surface, flesh colour was measured in reflectance as L*, a* and b*(CIE, 1978) by using a Minolta chromameter (CR-300 chromameter, Minolta Co, Japan). Colour was measured on each side of the half fruit faraway from the core and from the peel in three different points and it was taken in these same points soon after cutting (time 0) and at 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110 and 120 minutes of air exposure. In this way for each cultivar and location there were six mean colour measurements per each time t of air exposure, with a total of 132 observations.

In order to compare the behaviour of the different cultivar, the Browning Index (BI), the difference in Browning Index (ΔBI) and the difference in lightness (ΔL*) were considered. To calculate BI, the CIELAB colour parameters L*, a* and b* were converted into the XYZ tristimulus values according to the equations reported by Hunter (1975). Afterwards, BI was computed according to Eq.(1) (Perez-Gago et al., 2006):
\[ BI = \frac{(x - 0.31)/0.172}{\times 100} \]  \hspace{1cm} \text{Eq}(1) \\
where: \( x \) is the chromaticity coordinate calculated according to the following formula:

\[ x = \frac{X}{X+Y+Z} \]  \hspace{1cm} \text{Eq}(2) \\
The \( \Delta BI \) was computed according to \text{Eq.}(3):

\[ \Delta BI = BI_t - BI_0 \]  \hspace{1cm} \text{Eq}(3) \\
where: \( BI_t \) is the \( BI \) value at the time \( t \) of air exposure, and \( BI_0 \) is the \( BI \) value soon after cutting (at \( t=0 \)).

Similarly, the difference in lightness (\( \Delta L^* \)) was computed according to:

\[ \Delta L^* = L^*_{t} - L^*_{0} \]  \hspace{1cm} \text{Eq}(4) \\
where \( L^*_{0} \) is the \( L^* \) value measured at \( t=0 \) and \( L^*_{t} \) is the \( L^* \) value recorded at time \( t \) during the two hour of air exposure.

The values of \( \Delta L^* \) were used to score the extent of browning using the following \( \Delta L^* \) ranges for the classification: very slight (0–2.99); slight (–3–3.99); moderate (–4–5.99); severe (\( \leq – 6 \)) (Sapers and Douglas, 1987). Then for each cultivar and locality, the percentage distribution of the number of cases in each class of browning score was computed by pooling the observations for the following time intervals of air exposure: 1-10 min, 11-20 min, 21-30 min, 31-60 min and 61-120 min.

Statistical analysis was carried out using STATGRAPHICS version 7 (Manugistic Inc., Rockville MD, USA) software package. \( L^*, a^*, b^* \) and \( BI \) data from cultivars coming from the same locality were submitted to one-way analysis of variance (ANOVA procedure) considering as factor either the time of air exposure within the same cultivar or each cultivar within the same time of air exposure. Means were compared by Tukey’s test at \( P \leq 0.05 \).

\textbf{Results and Discussion}
According to different authors (Sapers and Douglas, 1987; Mastrocola et al., 1990), the decrease in L* (lightness loss) has been considered as the parameter better correlated with browning in apples as well as BI (Perez-Gago et al., 2006). Table 1 shows the L* and BI values at t=0 (soon after cutting), for all the cultivars and localities, while the trends of L* in function of time of air exposure are shown in Figure 1.

### Table 1. Lightness (L*) and Browning Index (BI) measured at t=0

(n=6; means ± standard error). Means followed by different letters are statistically different for P≤0.05 (Tukey's test). Lower-case letters refer to rows (locality within the same cultivar) and capital letters to column (cultivar within the same locality).

<table>
<thead>
<tr>
<th>Locality</th>
<th>Cultivar</th>
<th>Laimburg</th>
<th>Val Grana</th>
<th>Pinerolo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L*</td>
<td>BI</td>
<td>L*</td>
<td>BI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>±0.76 bBC</td>
<td>±0.78 aB</td>
<td>±0.30 aA</td>
</tr>
<tr>
<td>Golden Delicious</td>
<td>82.61</td>
<td>17.37</td>
<td>81.07</td>
<td>20.57</td>
</tr>
<tr>
<td>Golden Orange</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gala</td>
<td>81.52</td>
<td>22.06</td>
<td>82.63</td>
<td>18.33</td>
</tr>
<tr>
<td></td>
<td>±0.29 aBC</td>
<td>±0.70 abC</td>
<td>±0.26 aB</td>
<td>±2.49 aA</td>
</tr>
<tr>
<td>Pink Lady</td>
<td>83.25</td>
<td>15.77</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Granny Smith</td>
<td>80.70</td>
<td>12.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Braeburn</td>
<td>75.76</td>
<td>25.53</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Renetta</td>
<td>-</td>
<td>-</td>
<td>83.35</td>
<td>18.06</td>
</tr>
<tr>
<td></td>
<td>±0.42 aB</td>
<td>±0.85 aA</td>
<td>±0.35 bA</td>
<td>±1.60 aA</td>
</tr>
</tbody>
</table>

**Figure 1. Trends of L* values in function of time of air exposure**

*Bars refer to standard error of the mean.*
locality: Laimburg

locality: Val Grana

locality: Pinerolo
All the cultivars had the same L* and BI trends: L* values decreased, while BI increased with time. At $t=0$ ‘Golden Delicious’ from Laimburg and Pinerolo, ‘Golden Orange’, ‘Gala’ from Val Grana and Pinerolo, ‘Renetta’ from Val Grana and ‘Pink Lady’ showed statistically significant high values of L*, ranging from 84.5 to 82.6, while ‘Braeburn’ had the lowest L* value (75.76±0.87). After 10 min, only the L* value of ‘Renetta’ significantly decreased to 76.92±0.41 (apples from Pinerolo) and 77.22±0.15 (apples from Val Grana), whereas in all the other cultivars the decrease occurred after 30 min. By plotting the L* values of ‘Renetta’ cultivar against the logarithm of time in the first 10 min, the fitted linear model ($R^2 = 0.89$) had a high negative value of the slope (-4.6), thus indicating a severe browning already from the beginning of air exposure. In addition, at 30 min, L* values of ‘Braeburn’ (72.98±0.58) and of ‘Renetta’ (75.19±0.62) were lower than those of the other varieties. After 40-50 minutes, L* of nearly all the samples decreased to a minimum value, ranging from 80.98±0.38 (‘Golden Delicious’ from Pinerolo) to 72.09±0.74 (Braeburn), followed by a steady state till the end of air exposure. Exceptions were ‘Braeburn’ and ‘Granny Smith’, which, after a steady state from 40-50 min to 100 min, had a second significant decrease, reaching L* values of 71.14±0.72 and 74.35±0.65 respectively. At the end of air exposure, ‘Golden Orange’ (80.54±0.45), ‘Golden Delicious’ from Pinerolo (80.04±0.24) and from Laimburg (79.40±1.42), and ‘Pink Lady’ (79.05±0.51) were characterized by the highest values of L*.

Figure 2 shows the trend of $\Delta BI$ values during air exposure of all the cultivars and localities. The trend of $\Delta BI$ values for ‘Renetta’ cultivar was quite different from that of the other cultivars, due to its marked increase in a short time (ten minutes). At the moment of the cut (Table 1), ‘Granny Smith’ and ‘Pink Lady’ had the lowest BI values, while the highest were achieved by ‘Braeburn’, ‘Gala’ from Laimburg and Pinerolo, and ‘Golden Orange’.
During the first 10 min of air exposure, the BI values for ‘Renetta’ from both localities had the biggest increases, reaching the values of 33.98±2.36 (apples from Val Grana) and 31.27±1.63 (apples from Pinerolo), which were significantly higher respect to the other cultivars. Within 20-50 minutes all the cultivars reached the maximum value of ΔBI; afterwards, a quite steady state was achieved (Figure 2).

Figure 2. Browning Index difference (ΔBI) values in function of time of air exposure for apples cultivar
ΔBI

locality: Laimburg

locality: Val Grana

locality: Pinerolo

Golden Delicious  Gala  Braeburn  Granny Smith  Pink Lady

Golden Delicious  Gala  Renetta

Golden Delicious  Golden Orange  Gala  Renetta

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After 120 min, cultivar ‘Renetta’ reached the highest values of $BI$: 46.64±3.49 (apples from Val Grana) and 43.98±1.85 (apples from Pinerolo); cultivar ‘Gala’ from Pinerolo reached a high value too (41.66±0.87). Instead ‘Granny Smith’ (26.64±2.24), ‘Pink Lady’ (27.57±1.42) and ‘Golden Delicious’ from Laimburg (28.32±1.52) achieved the lowest $BI$ values.

The $\Delta L^*$ values calculated at each time of air exposure for each cultivar and locality (data not shown) were considered as index of browning (Sapers and Douglas, 1987). So, in Table 2, the percentage distribution of the four classes of browning (very slight, slight, moderate and severe) is reported for each cultivar, each locality and considering five intervals of time exposure: 1-10 min; 11-20 min; 21-30 min; 31-60 min; 61-120 min.

The results pointed out that within 10 min the cultivar ‘Renetta’ from both localities reached a severe browning, while all the other cultivars showed a very slight/slight browning, except for ‘Braeburn’, which presented moderate browning. In the range of 10-20 min all the cultivars, with the exception of ‘Renetta’, showed a high percentage value ($\geq$50%) of very slight browning. On the other hand, ‘Gala’ from Pinerolo, ‘Pink Lady’ and ‘Granny Smith’ fruit started showing a moderate browning and ‘Braeburn’ significantly increased this percentage value. Within 30 min, the percentage values were more distributed and all the cultivars (except ‘Golden Delicious’ from Val Grana, ‘Golden Orange’ and ‘Gala’ from
Laimburg) showed also moderate browning; ‘Gala’ from Pinerolo, in this range of time, also showed a percentage value of severe browning. After 60 min cultivar ‘Renetta’ from both localities reached a severe browning in the total of the experimental points (100%), while ‘Gala’ from Pinerolo in the 50% of the cases. As for the other cultivars, the cases were almost equally distributed among the different classes of browning. Within 120 min, also the cultivars ‘Gala’ from Laimburg, ‘Pink Lady’, ‘Granny Smith’ and ‘Braeburn’ showed severe browning, but only in less than 20% of cases.

In this preliminary study, the reported results showed that in the experimental conditions and in the season considered, the suitability of the apples to be processed into fresh-cut products depended both on cultivar and on locality. In particular, the cultivars ‘Golden Delicious’ from Laimburg and Pinerolo, ‘Golden Orange’ and ‘Pink Lady’ showed the best performances obtaining the highest values of L*, low values of BI during the tests, and with no or very low percentage of severe browning. ‘Gala’ (except for the Pinerolo locality) and ‘Granny Smith’ (up to 100 min) varieties also gave good performances. In contrast, ‘Renetta’ apples from both localities could be judged as the least suitable for fresh-cut processing as fruit reached high percentages of severe browning class already within 10-20 min, as well as high BI values. Also ‘Braeburn’ cultivar, characterized by low L* values coupled with moderate browning within 20 min, could be considered not much suitable for fresh-cut processing.

**Acknowledgements**

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**References**


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Table 2. Per cent distribution of $\Delta L^*$ values among the classes of severity of browning during specific ranges of time of air exposure.

Captions of classes of browning: vsl=very slight; sl=slight; m=moderate and s=severe.

<table>
<thead>
<tr>
<th>Cultivar</th>
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<th>Time intervals of air exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1-10 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td>vsl (%)</td>
</tr>
<tr>
<td>Golden Delicious</td>
<td>Laimburg</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Val Grana</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Pinerolo</td>
<td>100</td>
</tr>
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<tr>
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<td>93</td>
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<tr>
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<td>Val Grana</td>
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</tr>
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</tr>
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<tr>
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