doi: 10.17221/106/2016-HORTSCI

Preliminary evaluation of day-neutral strawberry cultivars cultivated in Italy using a qualitative integrated approach

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Abstract

Giuggioli N.R., Briano R., Alvariza P., Peano C. (2018): Preliminary evaluation of day-neutral strawberry cultivars cultivated in Italy using a qualitative integrated approach. Hort. Sci. (Prague), 45: 29–36.

In this study the texture profile, total soluble solids (TSS) and the fruit skin colour of four day-neutral strawberry cultivars cultivated in Italy ('Anabelle', 'Murano*', 'Portola*' and 'Triumph') was evaluated at four harvest times. The interrelationships of the analysed parameters were determined using principal component analysis in order to suggest the best commercial scenario (local market, supermarket retailer or export) for each cultivar. Data analysis related to texture and TSS contents revealed that 'Anabelle', 'Portola*' and 'Murano*' displayed unique characteristics, and that 'Triumph' showed lower values for these parameters. Due to its low hardness and cohesiveness values 'Anabelle' could be suited to a short supply chain; 'Portola*', meanwhile, might meet the requirements of a long supply chain, due to its high hardness and low TSS (P £ 0.05); 'Murano*' could be distinguished from the other cultivars by its high luminosity (ranging from 41.46–46.21 L*); while 'Triumph', due to its darkness (36.83–37.13 L*), could be suitable for a local/farmers' market.

Keywords: colour; *Fragaria* × *ananassa*; market; quality index; texture

The strawberry (*Fragaria* × *ananassa* Duch) crop is characterised, more than any other berry, by the number of different systems used for its production (tunnel, greenhouse, open field, soilless) and the numerous breeding programs used for this species (Capocasa et al. 2008; Martinelli, Michelangelo 2012). The major market channels for strawberries, as for the majority of fresh produce, are the regional and national wholesale markets and direct/local channels. Of the European countries, Italy is the fourth largest strawberry producer, producing approximately 140,000 t on a surface of 3,700 ha (Neri 2012; Turci 2013; Franceschini 2015). 'Portola*' is the major cultivar grown in Northern Italy, accounting for 60% of total strawberry production. Colour, pulp firmness, taste, flavour and nutritional value are considered the main quality parameters for consumer acceptance of fresh fruits (Kubota et al. 2012; Ornelas-Paz et al. 2013; Rios De Souza et al. 2014). Ares et al. (2009) developed an objective sensory quality index for strawberries, based on consumer perception; however, it was not suited to quality control in strawberries or their shelf life prediction, revealing the difficulty in evaluating product quality using a single index. Although strawberries have been classified as a non-climacteric fruit (Kader 1991), physicochemical changes continue to occur during storage. Strawberry cultivars with high pulp hardness could suit a supply chain with the longest transport time, due to their extended shelf life and resistance to mechanical damage; however, the influence of this property on texture and flavour perception at the time of consumption needs to be considered. The texture of strawberries has been widely reported (Caner et al. 2008; Kartal

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Table 1. Harvest time for strawberries and relative dates

Harvest time	Date
I	August 5, 2014
II	August 11, 2014
III	August 17, 2014
IV	August 23, 2014

et al. 2012; Aday, Caner 2013). However, texture was not correlated with the subjective assessment of freshness, which was more dependent on luminosity (Arce-Lopera et al. 2012). The freshness perception of strawberries involves the various attributes of appearance, odour, texture in hand and mouth, and flavour (Peneaú et al. 2007).

In this work strawberries were evaluated for several quality parameters (mechanical properties, total soluble solids (TSS) and colour) of importance to consumer acceptance. Four day-neutral strawberry cultivars ('Anabelle', 'Murano*', 'Portola*', and 'Triumph') grown in Northern Italy were investigated and the most appropriate market channel for each was suggested. The cultivars 'Anabelle', 'Murano*', 'Portola*' and 'Triumph' are present on the Italian varietal list (Faedi et al. 2014) and their characteristics are listed in Table 1.

MATERIAL AND METHODS

Plant material. Four day-neutral strawberry cultivars ('Anabelle', 'Murano*', 'Portola*' and 'Triumph') were grown in the greenhouse of Agrifrutta srl, a private company located at the foot of the mountains in Peveragno (Cuneo), Northwest Italy. All plants were grown in the same soilless tunnel.

Ninety fully red strawberries were harvested early in the morning, on a weekly basis from August 5 to August 23 in the year 2014 (Table 2), and once harvested, all cultivars were immediately transported at 4°C to the laboratory for qualitative analysis. To evaluate the texture profile analysis (TPA) characteristics and skin colour three replicates consisting of 30 individual fruits (90 fruits in total) were sampled for each cultivar and for each harvest time. The same fruits were mashed, homogenised and used for determination of TSS content and titratable acidity. Three replicates were measured for this last analysis. To best evaluate the interrelationships among analysed data within strawberry cultivars a principle component analysis (PCA) analysis was performed.

Texture profile analysis. Texture profile analysis (TPA) of the freshly harvested strawberries was performed using a TA.XTplus texture analyser (Stable Micro Systems Ltd., UK), with a 30 kg

Table 2. Fruit characteristics for all day-neutral varieties

Cultivar and origin	Patent	Owner	Fruit description	References
'Anabelle' (France)	–	Angier International	The dimension of the fruits is medium/small with a conical/oblongata shape. The external colour is red and the brightness is low. The colour of the pulp is orange/red with a low firmness. The fruit is sweet in taste and has low acidity. The aroma and organoleptic quality are medium/high.	Faedi 2014; Baroni et al. 2015
'Portola*' (USA)	2008/1505 (EU) 28654 (EU)	Davis, California University	The dimension of the fruits is big with a conical shape. The external colour is bright red and the brightness is elevated. The firmness of the fruits is high.	Shaw, Larson 2009
'Murano*' (Italy)	13694935 (US) 2012/1731 (EU)	CIV, Consorzio Italiano Vivaisti	The dimension of the fruits is medium/big with a conical shape. The external colour is red and the brightness is high. The colour of the pulp is light red with a high firmness. The sweet taste and acidity are medium. The aroma and organoleptic quality are medium.	Faedi 2014; Baroni et al. 2015
'Triumph' (USA)	US 20140157465 P1	Plant Science, Inc.	The dimension of the fruits is medium with a conical shape. The external colour of the berries is red (ranging from red to dark red), the glossiness range is from medium to strong. The firmness of the fruits is medium, the quality is good and the fruit aroma is good.	Ackerman et al. 2014

*cultivars that have the patent

doi: 10.17221/106/2016-HORTSCI

Table 3. Description of the TPA, sensory parameters and calculations

TPA Parameters	Description	Sensory	Calculation
Hardness (N)	Maximum force required to compress the sample	Force required to compress a substance between molar teeth	The peak force of the first compression cycle
Cohesiveness (dimensionless)	Extent to which a material can be deformed before it ruptures	Degree to which a substance is compressed between the teeth before it breaks	Measured as the area of work during the second compression divided by the area of work during the first compression
Springiness (elasticity) (dimensionless)	How well a product physically springs back after it has been deformed during the first compression. The spring-back is measured at the downstroke of the second compression.	Degree to which a product returns to its original shape	Distance of the detected height of the product on the second compression
Chewiness (N)	Energy required to masticate a solid food to steady state for swallowing	Length of time required to masticate the sample, at a constant rate of force application, to reduce it to a consistency suitable for swallowing	Gumminess × springiness
Gumminess (N)	Energy required to disintegrate a semi-solid material to a state ready for swallowing: a product of a low degree of hardness and a high degree of cohesiveness	Denseness that persists throughout mastication: energy required to disintegrate a semi-solid material to a state suitable for swallowing	Hardness × cohesiveness
Resilience (dimensionless)	How well a product 'fights' to regain its original position	–	The area during the withdrawal of the first compression, divided by the area of the first compression

references: Yang et al. 2006; Singh et al. 2013; Nishinari et al. 2013

load cell. Compression tests were performed on whole fresh fruits maintained at room temperature (18°C ± 1°C) with the following parameters: a 75-mm aluminium compression plate (P/75), 5 mm/s pre-test speed, 1 mm/s test speed, 8 mm/s post-test speed, penetration distance 4 mm and rest period of 5 s between cycles, trigger force 1.0 N and 5 N trigger force. Values of hardness, adhesiveness, cohesiveness, springiness, gumminess, chewiness and resilience were automatically calculated from the resulting force-time curve using Texture Expert Version 1.17 software (Caner et al. 2008). The definitions of each textural parameter are reported in Table 3. The average of 90 fruits for each cultivar and harvesting time were calculated.

Total soluble solids and fruit skin colour. The TSS of juice extracted from each strawberry was measured using an Atago Pal-1 pocket refractometer (Atago Co. Ltd., Japan), and expressed as °Brix at 20°C.

The skin colour of each fruit was measured using a tristimulus reflectance colorimeter (Minolta Chroma Meter, Model CR-200b, Japan) equipped with an 8-mm diameter measuring area. Colour was recorded using the CIE$L^*a^*b^*$ uniform colour space, where L^* indicates lightness, a^* indicates chromaticity on a green (–) to red (+) axis, and b^* chromaticity on a blue (–) to yellow (+) axis. The average TSS and surface colour of 90 fruits for each cultivar and harvesting time were calculated.

Statistical analysis. All statistical analyses were performed using SPSS Statistics 22 software package (2013, IBM, Italy) for Mac. The obtained data were analysed using a two-way analysis of variance (ANOVA), and the means were separated using Tukey's test ($P \leq 0.05$). When the interactions were significant, the mean values were compared using a least significant difference (LSD) multiple range test, at $P \leq 0.05$ significance. To correlate the combined parameters of TPA, TSS and colour, the data were standardised and a PCA was performed. A varimix rotation was used to restrict the components to those that had high factor loadings.

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Table 4. Multivariate linear analysis for texture profile analysis, total soluble solids (TSS), (°Brix) and colour parameters (L^*, a^* and b^*) of strawberry cv. 'Anabelle', 'Portola*', 'Murano*' and 'Triumph'

	Hardness	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience	TSS	L^*	a^*	b^*
Cultivar	0.01	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harvesting time	0.01	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.00
Cultivar*harvesting time	0.01	0.63	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

when interactions were significant, the mean values were compared using a least significant difference (LSD) multiple range test with $P < 0.05$ considered significant; L^* – lightness; a^* – chromaticity on a green (–) to red (+) axis; b^* – chromaticity on a blue (–) to yellow (+) axis

RESULTS AND DISCUSSION

Texture profile analysis

The TPA of strawberries has been previously used to examine differences in the quality of strawberry cultivars (Rasing et al. 2003; Caner et al. 2008). In the present study, multivariate linear analysis of the acquired TPA data was used to identify differences among four strawberry cultivars ('Anabelle', 'Murano*', 'Portola*' and 'Triumph'), as a function of harvest time (Table 4). All the considered TPA parameters, with the exception of adhesiveness and springiness, were influenced by cultivar and harvest time, and their interaction. Hardness, adhesiveness and cohesiveness are the main textural attributes associated with the sensory and rheological properties of organic matrices (Nishinari et al. 2013). Hence, Fig. 1 limits the TPA to these three textural attributes, which are further discussed herein.

Hardness is the max. force required to compress the sample and was calculated from the peak force of the first compression cycle (Fig. 1a). The four strawberry cultivars showed significant differences (P £ 0.05) in hardness at each harvest time. Hardness values on August 5 (first harvesting time) were 8,118.2 ± 1.75, 7,337.4 ± 1.30, 5,021.1 ± 1.45 and 4,517.2 N ± 1.59 for 'Portola*', 'Murano*', 'Triumph' and 'Anabelle', respectively. 'Portola*' was the firmest throughout the entire harvest period, followed in decreasing order by 'Murano*' > 'Triumph' > 'Anabelle'. Relative hardness for each cultivar was higher on the final two harvest dates compared to the first two (differences of +3.68%, +22.67%, +22.42% and +34.55% for 'Anabelle', 'Portola*', 'Murano*' and 'Triumph', respectively, between the first and the last harvest). This trend is probably due to the 5°C drop in temperature at the end of the second harvest time (data not shown) and confirms the positive relationship between the temperature of the fruit and its firmness in the strawberry (Rose et al. 1934).

Adhesiveness represents the tendency to be sticky and describes the mucilaginous nature of the strawberry. No significant differences in adhesiveness were observed among the cultivars, irrespective of the harvest date. However, the lowest adhesiveness values were recorded on August 17 and 23 (last two harvest dates; Fig. 1b). Adhesiveness is an important factor in post-harvest handling of strawberries, hence August 17 and 23 were key harvest dates. Fruits that undergo long transport periods require low adhesiveness values at harvest, as this parameter can increase with storage (Caner et al. 2008). Solubilisation of pectin material in the middle lamellae (Caner et al. 2008) of the fruit corresponds to decreased cohesiveness. Furthermore, cohesiveness plays an important role in mouthfeel towards the end of mastication by the molar teeth (Bourne 2002). 'Anabelle' had significantly lower cohesiveness than the other cultivars throughout the harvesting period. On the second and fourth harvest, 'Portola*', 'Murano*' and 'Triumph' had similar cohesiveness ($P > 0.05$).

Total soluble solids

The TSS is mainly influenced by the total sugars and organic acids, which, in turn, are influenced by the cultivar and stage of ripeness. All four cultivars had significantly different TSS values at each

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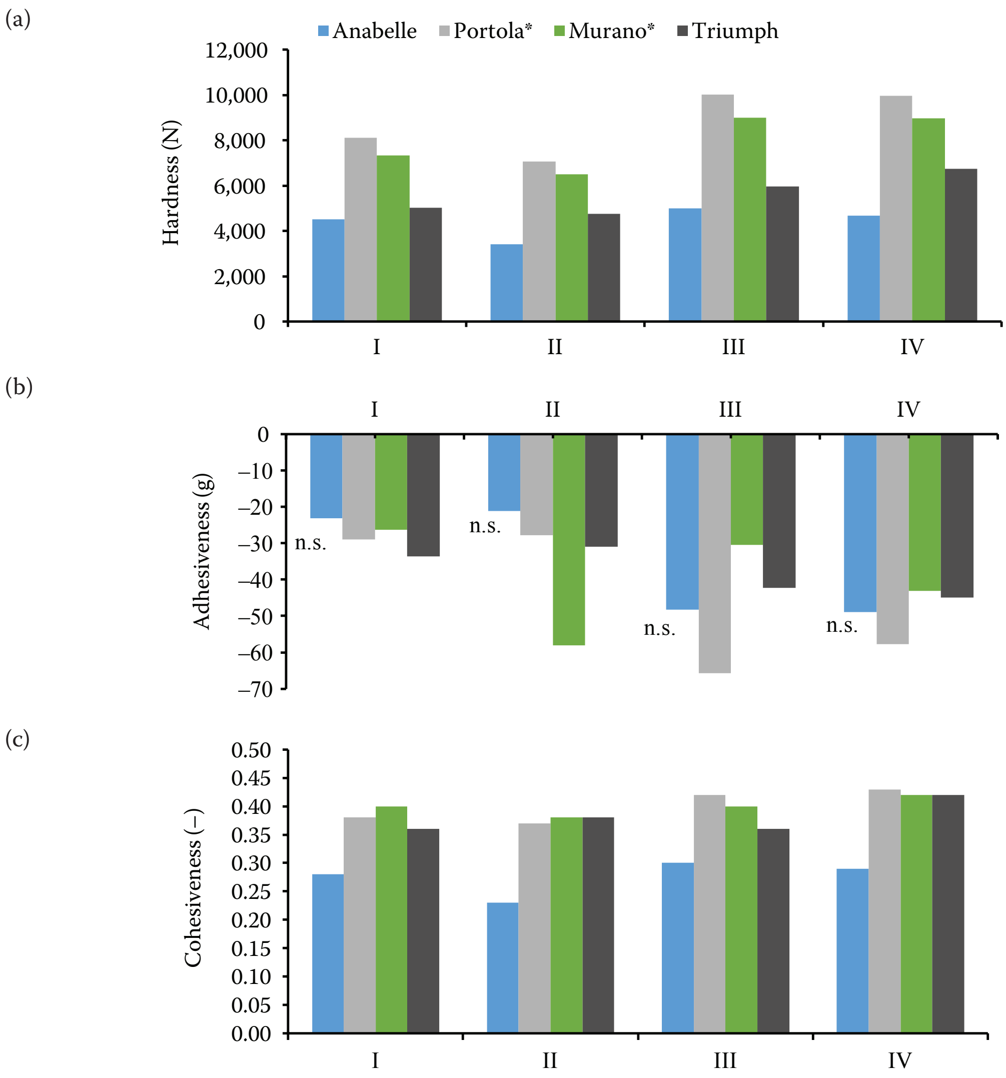

Fig. 1. Texture profile analysis (TPA): (a) hardness, (b) adhesiveness, and (c) cohesiveness for the 'Anabelle, 'Portola*', 'Murano*' and 'Triumph' during the 4 harvesting times
the means regarding the harvest time, followed by different letters are significantly different at $P \leq 0.05$ according to Tukey's test

harvest time (Table 3, Fig. 2; $P \leq 0.05$). 'Anabelle' had the highest TSS, ranging from 7.79–9.06°Brix. In contrast, 'Portola*' had the lowest TSS, ranging from 5.64–5.77°Brix. Soft strawberries are perceived to have high sweetness even though they may have soluble sugar contents similar to those of harder fruits (Kohyama et al. 2013). The TSS values of all four cultivars, with the exception of 'Portola*', increased significantly as a function of harvest time (data not shown). Differences in strawberry TSS across harvest dates have been associated with changes in plant physiological state and environmental conditions. According to Hasing et al. (2013), cultivars that maintain a stable TSS throughout the fruiting season would be highly desirable, due to their uniform eating quality. For this reason, 'Portola*' would be the preferred cultivar to maintain eating quality at the end of the season when the overall market supply increases, but also when environmental conditions cause adverse effects associated with high TSS in the fruit.

Fruit skin colour

Anthocyanins, carotenoids and chlorophylls are the main pigments responsible for the colour of strawberries (Nunes et al. 2006). Bright, red straw-

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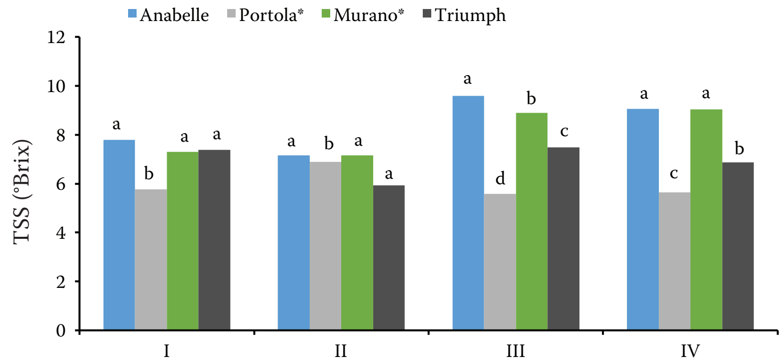

Fig. 2. Total soluble solids (TSS) (°Brix) for the 4 strawberry cultivars during the 4 harvesting times
means regarding the harvest time, followed by different letters are significantly different at $P \leq 0.05$ according to Tukey's test

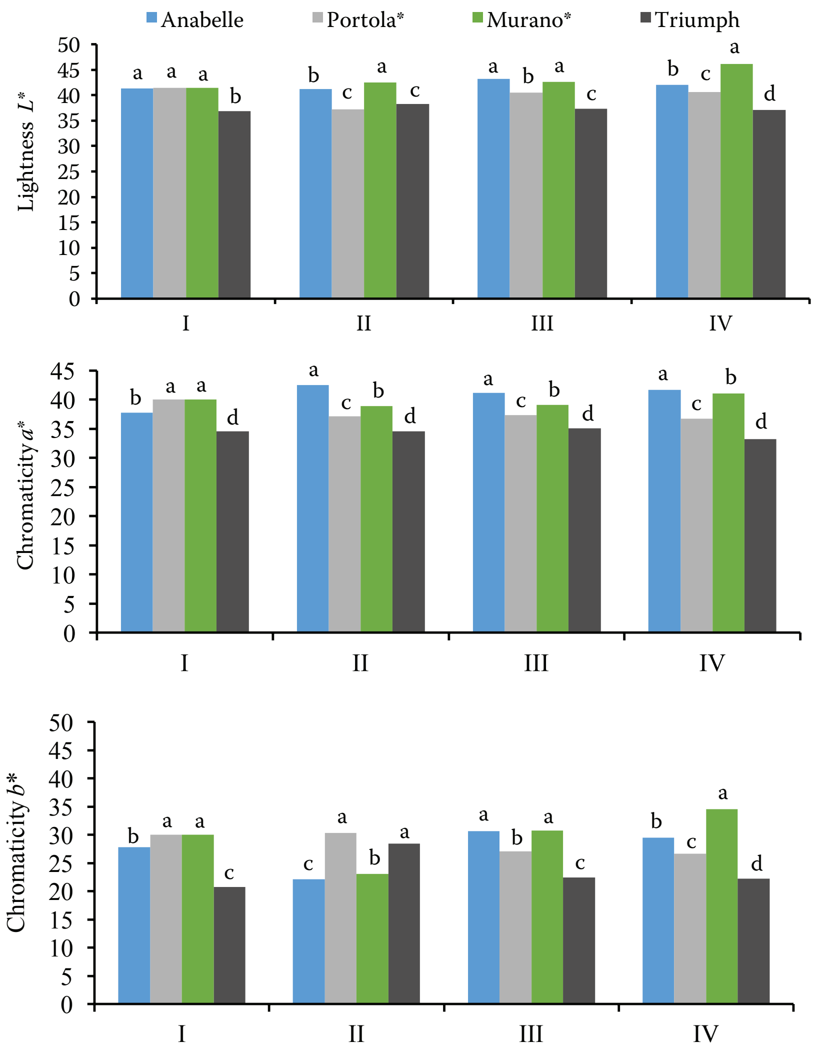

Fig. 3. Fruit external colour parameters: (a) lightness (L^*), (b) chromaticity on a green (–) to red (+) axis (a^*), and (c) chromaticity on a blue (–) to yellow (+) axis (b^*; (c)) for the 4 strawberry cultivars during the 4 harvesting times
the means regarding the harvest time, followed by different letters are significantly different at $P \leq 0.05$ according to Tukey's test

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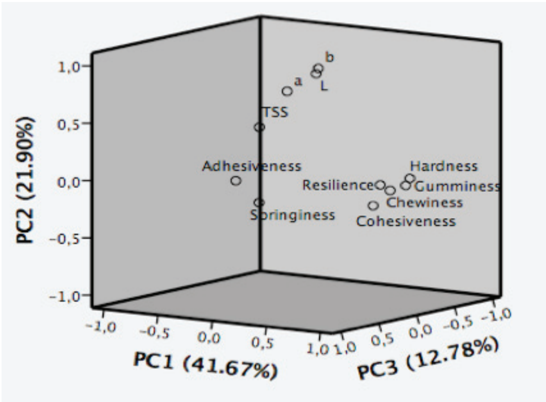

Fig. 4. Principal component analysis (PCA) for the 4 strawberry cultivars during the 4 harvesting times

berries are more suited to supermarkets compared to dark strawberries, due to high consumer acceptance. Table 3 shows that L^* was strongly influenced by the cultivar and harvest time, and their interaction. The highest L^* values were obtained for 'Murano*' and ranged from 41.46–46.21 (L^*), while 'Triumph' had the lowest with a L^* range of 36.83–37.13 (Fig. 3). Statistically significant L^* differences among all the cultivars were observed from the start of the second harvest time until the final harvest (August 23), at which stage the following L^* values were obtained: 'Anabelle' 42.10 ± 2.92 (L^*); 'Portola*' 40.60 ± 3.66 (L^*); 'Murano*' 46.21 ± 3.96 (L^*) and 'Triumph' 37.13 ± 3.22 (L^*).

Principal component analysis

PCA is a useful tool to identify patterns in data and highlight their similarities and differences (Rodriguez-Delgado et al. 2002; Šamec et al. 2016). PCA has been used successfully to evaluate the interrelationships among certain physical and chemical attributes within strawberry cultivars (Šamec et al. 2016). The PCA used in the present study showed that 74.87% of the variability was explained by the first three components: PC1, PC2 and PC3 accounted for 41.67%, 21.90% and 12.78%, respectively, of the variability (Fig. 4). The fruit skin colour parameters (L^*, a^* and b^* values) and TSS contents were markedly differentiated from the texture parameters. Indeed, they were grouped in PC2, which can be described as the colourfulness-quality group. Most of the TPA parameters (hardness, gumminess, chewiness, cohesiveness and resilience) were grouped together in PC1, while springiness and adhesiveness were combined in PC3. This was probably because springiness and adhesiveness are primarily correlated with the viscosity properties of an organic matrix.

CONCLUSION

On the basis of this preliminary study of day-neutral cultivars cultivated in Northern Italy, it can be concluded that 'Anabelle', 'Portola*', 'Murano*' and 'Triumph' had distinct attributes when measured against a single qualitative standard. However, evaluation of their qualities against multiple indices was not possible. The cultivars were distinguished based on their texture, colour and TSS, and, therefore, these parameters are a potentially useful means of identifying their most appropriate market channels. 'Anabelle', 'Portola*' and 'Murano*' exhibited unique texture characteristics and TSS contents; 'Triumph' showed lower values for these characteristics. 'Anabelle' could be ideal for a short supply chain, such as a farmers' market, as it displayed the lowest hardness and cohesiveness, suggesting that it may be susceptible to the deformation stresses that occur during transport and shipping. Its high TSS content can be considered more suitable and may be appreciated by consumers particularly interested in traditional taste. 'Portola*' exhibited the highest hardness and lowest degree of change in TSS throughout the harvest period, suggesting that it may have a relatively long shelf life and suit the longest supply chain. 'Murano*' was differentiated from the other cultivars by its high L^*. This cultivar showed intermediate texture characteristics, and, therefore, could be suited to either a short or long supply chain. Due to its dark colour, 'Triumph' may suit a local/farmers' market. All four cultivars should be further evaluated with respect to nutraceutical attributes and flavour, as well as post-harvest properties.

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Received for publication May 26, 2016
Accepted after corrections January 2017