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Impact of different advanced ripening stages on berry texture properties of ‘Red Globe’ and ‘Crimson Seedless’ table grape cultivars (*Vitis vinifera* L.)

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Abstract

The impact of different ripening stages on berry texture properties of sorted 'Red Globe' and 'Crimson Seedless' table grapes was evaluated. Density sorting at different harvest dates was utilised to obtain homogeneous samples for each ripening stage. At the same ripening stage, 'Red Globe' berries were more firm, cohesive, springy, chewy and resilient but less hard and gummy than 'Crimson Seedless'. Particularly for cv. Red Globe, the choice of the ripening stage at harvest could be a determinant for the berry quality because riper berries were associated with higher skin thickness values (+25%). The berry hardness and gumminess of 'Crimson Seedless' decreased significantly during ripening (-50%), and these parameters were most influenced by the berry size. Conversely, berry cohesiveness can be used as a ripeness predictor of table grapes because the changes during the ripening process were independent of berry size. The peduncle detachment resistance of the berry in the Crimson Seedless grapes decreased to values lower than 3.4 N, negatively affecting the quality attributes of the berry.

Keywords: texture analysis, skin hardness, skin thickness, berry firmness, texture profile analysis (TPA), table grapes.

1. Introduction

Table grape (*Vitis vinifera* L.) is one of the most cultivated and consumed fruits (fresh and raisin) worldwide. According to the annual statistics published by the International Organization of Vine and Wine (OIV), the production intended for direct fresh consumption increased during the last five years. Although many table grape varieties are known and have been classified using genetic and ampelographic methods (OIV, 2009), not all varieties possess the same diffusion and commercial importance. ‘Red Globe’ and ‘Crimson Seedless’ are among the most cultivated, most commercially important and most studied cultivars, as evidenced by the numerous scientific studies that have been conducted on these varieties. Briefly, recent studies on these varieties have considered several aspects that influence berry quality, such as cultural practices (Human and Bindon, 2008; Lurie et al., 2010; Peppi et al., 2008), colour characteristics (Bahar et al., 2012; Lurie et al., 2010; Peppi et al., 2008), chemical parameters, phenolic composition and their evolution during ripening (Crupi et al., 2012; Jayasena and Cameron, 2008; Muñoz-Robredo et al., 2011; Singh Brar et al., 2008), antioxidant activities (Baiano and Terracone, 2011; Lutz et al., 2011; Molina-Quijada et al., 2010), protein content and enzymatic activities (Forte et al., 2009; López-Miranda et al., 2011), post-harvest storage conditions (Jayasena and Cameron, 2009; Sabir and Sabir, 2013), and packaging atmosphere and materials (Candir et al., 2012; Conte et al., 2012; Neves et al., 2008; Ustun et al., 2012). However, information regarding the instrumental texture properties of ‘Red Globe’ and ‘Crimson Seedless’ berries remains unknown for fresh consumption. The berries’ mechanical properties are considered the most important factors that affect the eating quality (Rolle et al., 2012a).

As defined by ISO 5492:2009, which states that “all mechanical, geometrical, surface and body attributes of a product perceptible by means of kinaesthesia and somesthesia

receptors, and (where appropriate) visual and auditory receptors from the first bite to final swallowing”, the textural properties of table grapes are important attributes for consumer acceptance. Historically, researchers have used many terms, such as fleshy, firm, crisp, tough, tender, melting and soft, to describe the berry/pulp consistency; these descriptions were summarised by Sato et al. (1997). The second edition of the OIV descriptor list for grape varieties and *Vitis* species with the Code OIV n° 235 – ‘Berry: Firmness of flesh’ classifies table grape cultivars into the following three groups compared to reference cultivars: soft, slightly firm and very firm (OIV, 2009). Additional sensory descriptors, such as skin friability, skin thickness and flesh firmness, have been proposed to characterise commercial table grape cultivars (Cliff et al., 1996). Alternatively, instrumental texture variables, such as berry firmness, are considered a measurement of freshness (Vargas et al., 2001). More recently, texture profile analysis (TPA) has provided instrumental parameters that have been proposed as physical markers to characterise and compare table grape varieties (Rolle et al., 2011a) and as useful variables to monitor their post-harvest shelf-life during storage (Deng et al., 2005). Although instrumental measurements are often preferred to sensory evaluations in the food industry because the instrumental measurements are more objective and can be more easily used to compare data from different sources, scientific contributions on direct relationships between sensory and mechanical properties for table and wine grapes are still scarce (Le Moigne et al., 2008; Sato and Yamada, 2003).

To expand the existing knowledge regarding the instrumental mechanical properties of table grapes, especially for ‘Red Globe’ and ‘Crimson Seedless’, this study was designed to accomplish the following aims: *i*) characterise these cultivars with respect to the mechanical properties of the berries harvested at different stages of ripening and density sorted by flotation, *ii*) evaluate the skin thickness and hardness, the pedicel detachment resistance and

whole-berry texture parameters during ripening, and *iii*) investigate the relationship between texture variables and berry size.

2. Materials and methods

2.1 Grape samples

Vitis vinifera L. cultivar ‘Red Globe’ and ‘Crimson Seedless’ table grapes were collected from a commercial vineyard located in the northwestern region of the Bari province (Apulia Region, Southern Italy, 41°9’0’’N 16°24’0’’E, 230 m a.s.l.). The vines, which were grafted onto the ‘140 Ru’ rootstock and planted at 2.4 x 2.4 m, were trained to the tendone system ‘Puglia type’. At the time of the winter pruning, the vines were cane-pruned, leaving 4 canes of 10/12 buds each for cv. Red Globe and 6 canes of 15 buds each for cv. Crimson Seedless. The ‘Red Globe’ and ‘Crimson Seedless’ samples were harvested during periods of four (26 August-30 September) and five (2-30 September) consecutive weeks in 2010, respectively. Approximately 10 kg of berries for each sampling date and cultivar were randomly picked with attached pedicels from 500 vines. The berries were picked individually, three or four berries from each cluster. To define real, advanced physiological stages to improve the intra-sample homogeneity, the berries were sorted according to their density by flotation as described by Fournand et al. (2006). For the first week, the least dense classes were selected (A for ‘Red Globe’ and B for ‘Crimson Seedless’), and for the last week, the most dense classes were selected (D for ‘Red Globe’ and F for ‘Crimson Seedless’); this scheme was designed to emphasise the physiological differences among the sampling dates. For each date, the class of retained berries generally corresponded to the major class. Using the protocol described by Rolle et al. (2011b), the densimetric flotation of the berries was

performed in various saline solutions (ranging from 60 to 150 g/L sodium chloride), and the berries belonging to the following density classes were analysed: A = 1055 kg/m³, B = 1062 kg/m³, C = 1069 kg/m³, D = 1075 kg/m³, E = 1081 kg/m³, and F = 1088 kg/m³. The 'floating' berries were washed with water and visually inspected prior to analysis; any berries with damaged skins were discarded. For both the density class and variety, a sub-sample of 30 sorted berries was used for each texture test.

2.2 Berry size

Before performing the texture profile analysis (TPA) test, each berry's size was measured. The longitudinal diameter (*L*) and the transversal diameter (*I*) were measured using callipers with 0.1 mm accuracy. The volume was then calculated by comparing the berry form to an ellipsoid based on the following equation: volume (cm³) = $4 \pi a b c / 3$, where $a = b = I/2$, and $c = L/2$ (Río Segade et al., 2011a).

2.3 Technological maturity parameters

Following the TPA test, all of the analysed berries were separated in three replicates and manually crushed. The grape that was obtained for each sample was centrifuged and then used to determine the primary technological maturity parameters. The total soluble solids concentration (°Brix, as SSC) was measured using an Atago 0-32 °Brix temperature compensating refractometer (Atago Co., Tokyo, Japan), and the pH was determined by potentiometry using a Crison electrode (Carpi, Italy). Titratable acidity (TA), expressed as g/L tartaric acid, was estimated using the Official OIV method (OIV, 2008a). The glucose,

fructose, citric acid, tartaric acid and malic acid contents were measured with an HPLC system (Thermo Electron Co., Waltham, MA, USA) equipped with a UV detector (UV100) at 210 nm and a refractive index detector (RI-150). The analyses were performed isocratically at 0.8 mL/min flow-rate and 65° C column temperature with a 300 mm × 7.8 mm i.d. cation exchange column (Aminex HPX-87H) and a Cation H⁺ Microguard cartridge (Bio-Rad Laboratories, Hercules, CA, USA). The mobile phase was 0.0013 mol/L H₂SO₄ (Giordano et al., 2009). The data treatment was performed using the ChromQuestTM chromatography data system (ThermoQuest, Inc., San Jose, CA, USA).

2.4 Texture Analysis tests

A Universal Testing Machine (UTM) TAxT2i texture analyser (Stable Micro System, Godalming, Surrey, UK) equipped with a HDP/90 platform and a 5 kg load cell was used. All of the data acquisitions were performed at 400 Hz, and the mechanical properties were calculated from force-distance curves using the Texture Expert Exceed software program version 2.54 for Windows 2000 (Stable Micro System, Godalming, Surrey, UK). The instrumental texture tests were performed and the mechanical variables were measured and defined according to the methods described by Letaief et al. (2008).

2.4.1 Skin mechanical properties

Skin hardness was evaluated by a puncture test using an SMS P/2N needle probe (Stable Micro System, Godalming, Surrey, UK) and a test speed of 1 mm/s. The berries were individually punctured in the lateral face and the following three parameters were

measured: berry skin break force (N, as F_{sk}), berry skin break energy (mJ, as W_{sk}) and skin resistance to the axial deformation (N/mm, as E_{sk}). The measurement of the skin thickness (μm , as Sp_{sk}), which was performed by a compression test using an SMS P/2 flat cylindrical probe and a test speed of 0.2 mm/s, required the manual separation of a piece of skin (ca. 0.25 cm^2) from the lateral side of each berry with a razor blade and its subsequent drying with adsorbent paper. An instrumental trigger threshold equal to 0.05 N was inserted, allowing the elimination of the 'tail' effect due to the postponement of the contact point (Río Segade et al., 2011a).

2.4.2 Whole berry mechanical properties

The mechanical properties of the whole berry were evaluated by a TPA test. Each whole berry was compressed in the equatorial position using an SMS P/35 flat cylindrical probe (Stable Micro System, Godalming, Surrey, UK) under 25% deformation with a waiting time between the two bites of two seconds and a test speed of 1 mm/s. From the force-time (deformation) curves, the typical TPA texture parameters were calculated by the software program as follows: hardness (N), cohesiveness (adimensional), gumminess (N), springiness (mm), chewiness (mJ) and resilience (adimensional) (Rolle et al., 2011a). Berry firmness, which was expressed in terms of millimetres of deformation under a fixed force of 3 N, was calculated using the same curve from the first compression (Bellincontro et al., 2009).

2.4.3 Peduncle detachment resistance

The peduncle detachment resistance was determined by a traction test carried out at a speed of 1 mm/s. In this test, the peduncle of the berry was anchored to the pliers of the

SMS A/PS probe (Stable Micro System, Godalming, Surrey, UK) that was modified with a rigid arm (Rolle et al., 2012a). During the traction, the peduncle passed through the perforated platform of the UTM (hole diameter of 5 mm), while the berry was blocked, permitting the determination of the peduncle detachment maximum force (N, as F_{ped}) and energy (mJ, as W_{ped}) (Rolle et al., 2012a).

2.5 Statistical analysis

The statistical analyses were performed using the statistical software package SPSS (version 17.0; SPSS Inc., Chicago, IL, USA). The Tukey-b test for $p < 0.05$ was used to establish significant differences with a one-way analysis of variance (ANOVA). Pearson correlation coefficients were calculated to determine significant correlations.

3. Results

3.1 Berry size and technological maturity parameters

According to OIV resolution VITI 1/2008 and UE Commission Regulation 543/2011, table grapes are considered to be ripe at $\text{SSC} \geq 16$ °Brix or when the SSC (expressed as g/L)/TA (expressed as g/L tartaric acid) ratio is higher than 20; in the particular case of seedless varieties, ripeness is considered at $\text{SSC} \geq 14$ °Brix. As reported in Table 1, both ‘Red Globe’ and ‘Crimson Seedless’ grapes reached the maturity requirements at all of the different ripening stages in this trial.

As expected, the total soluble solid content (SSC) increased with increasing berry density, whereas the titratable acidity (TA), tartaric and malic acids generally decreased.

Furthermore, the SSC/TA ratio increased regularly during the grape ripening process; the differences between two successive stages ranged from 2.5 to 6.8 for 'Red Globe' and from 0.9 to 7.9 for 'Crimson Seedless'. Instead, the glucose/fructose ratio and the citric acid content were not related to the berry density and/or the advance in ripening. At similar sugar contents, the two cultivars showed large difference in the SSC/TA ratio, glucose/fructose ratio, and acid contents and profiles.

Smaller berry sizes were associated with higher density values only in 'Crimson Seedless', whereas no relationship was found in 'Red Globe'.

3.2 Texture Analysis

3.2.1 Skin mechanical properties

Table 2 shows the parameters that define the berry skin hardness, such as skin break force (F_{sk}) and skin break energy (W_{sk}), the berry skin stiffness (E_{sk}) and the berry skin thickness (Sp_{sk}). Because the data were highly variable, the impact of the ripening stage on these mechanical variables was not clearly visible. However, a general tendency toward increasing skin hardness was observed during ripening, and increasing SSC was observed in the juice. For both cultivars, the highest values were observed at the last ripening stage, that is D (0.540 N, 0.402 mJ) and F (0.519 N, 0.348 mJ) for 'Red Globe' and 'Crimson Seedless', respectively. Regarding the skin thickness, only the Sp_{sk} values of the 'Red Globe' berries showed a significant change during ripening, with an average increase of approximately 70 μm from ripening stages A to D. Nevertheless, this skin mechanical property showed similar behaviour to the 'Crimson Seedless' berries, in particular at the last ripening stage. Meanwhile, no trends were observed in the E_{sk} parameter for either cultivar. Relationships

among the berry skin mechanical characteristics and berry size were not investigated in this study.

3.2.2 *Whole berry mechanical properties*

In contrast to the skin physico-mechanical variables, many texture parameters of the whole berry changed significantly during the fruit ripening process (Table 3). These modifications were particularly evident for ‘Crimson Seedless’, in which all of the parameters except for resilience (i.e., the measurement of how well the product fights to regain its original position (Letaief et al., 2008)) changed during ripening. For ‘Red Globe’, only berry cohesiveness, which is a ‘measurement of the strength of the internal bonds making up the body of the product’, showed a significant increasing trend. Berry hardness, the ‘measurement of the force necessary to attain a given deformation’, appreciably decreased from the first to last week of sampling; the decreases were -22% (3.67 N) and -51% (10.12 N) for ‘Red Globe’ and ‘Crimson Seedless’, respectively. A similar trend was detected for berry gumminess, the ‘measurement of the force necessary to disintegrate a semisolid food until it is ready for swallowing’, and chewiness, the ‘measurement of the energy necessary to chew a solid food until it is ready for swallowing’; these instrumental variables are both strongly dependent on berry hardness (Rolle et al., 2012a). In ‘Crimson Seedless’ berries, a different behaviour was always observed for berry firmness and springiness. The first variable increased (+31%, 0.60 mm), whereas the second variable decreased (-15%, 0.54N) with higher values of SSC. Although berry springiness, which is expressed as the ‘distance recovered by the sample during the time comprised between the end of the first bite and the start of the second bite’, and firmness, which is expressed in terms of ‘millimetres of deformation under a fixed force’, showed an inverse trend, no significant correlation was found between these two variables. At the same ripening stage, ‘Red Globe’ berries were

more firm, cohesive, springy, chewy and resilient but displayed lower hardness and gumminess compared to the ‘Crimson Seedless’ berries.

The relationships among the Texture Profile Analysis (TPA) parameters and berry size were investigated only for ‘Crimson Seedless’. High and significant correlation coefficients ($p < 0.01$) were found among each of the whole-berry mechanical variables and the berry volume. To minimise the berry size’s effect on the instrumental texture data, the TPA variables were normalised to the berry volume (Table 4). By comparing the data reported in Table 3 with those in Table 4, it was possible to determine that the effect of the ripening stage remained similar for the mechanical behaviours of berry firmness and springiness. The effect was amplified (higher differences in the values among ripening stages) for cohesiveness and resilience, and it was reduced for chewiness. Berry hardness and gumminess were the parameters that were most influenced by the berry size; therefore, the ripening stage effect was not evident for these texture characteristics after normalisation. As evidenced in Table 1, a significant relationship among density class and berry size was found observed; smaller berries were associated with higher SSC values. Additionally, following normalisation, berry firmness, cohesiveness and resilience showed similar trends during grape ripening in relation to the respective parameters without normalisation. Otherwise, the normalised berry springiness changed the trend such that the values increased between ripening stages B to F. Thus, at equal volumes, berries with a high SSC were characterised by a lower consistence (higher value of firmness) but a higher ability to recover the initial form (higher value of springiness).

3.2.3 *Peduncle detachment resistance*

The resistance of the berry to peduncle detachment was strongly influenced by the ripening stage (Table 5). In particular, the peduncle detachment maximum force (F_{ped})

decreased with the increase in the berry density, although the two cultivars showed different behaviours. In ‘Crimson Seedless’, F_{ped} decreased progressively during the five weeks of sampling (approximately 1.85 N per week), while in ‘Red Globe’, the change was significant only during the last week (from C to D, 2.20 N). Although the peduncle detachment energy (W_{ped}) showed a pattern similar to that of F_{ped} , no significant changes were observed during ‘Red Globe’ ripening.

4. Discussion

Because no biological process occurs simultaneously within all plant organs, grapes within the same cluster do not ripen homogeneously (Río Segade et al., 2013). Moreover, the vine location within the vineyard and the cluster position on the vine can accentuate differences in the ripening rate. The latter is known to be primarily influenced by variables related to exposure, microclimatic conditions, cluster rank and soil characteristics. Therefore, heterogeneous ripening is one of the major factors in typifying the grape variety features. The distribution of the berries in different density classes was observed in the vineyard during the first phase of the ripening process, and their allocation percentage changed during the SSC increase as previously described (Rolle et al., 2011b). At each ripening stage in this trial, ‘Crimson Seedless’ and ‘Red Globe’ table grapes were similarly dispersed according to the density following a Gaussian bell-shape distribution (data not shown), confirming the same behaviour found for ‘Cabernet Sauvignon’ (Kontoudakis et al., 2011) and ‘Cabernet Franc’ (Zouid et al., 2013) wine grapes. In the present study, the sugar content of the grapes belonging to the more representative density classes corresponded generally to the vineyard average.

Only the berries of 'Crimson Seedless' belonging to the density classes E and F were characterised by a higher SSC content with respect to the average vineyard value. In general, the difference in the sugar contents of the berries belonging to two consecutive density classes was ~17 g/L as previously reported by Fournand et al. (2006). In 'Red Globe', similar differences in sugar contents were found among the density classes with the exception of the riper berries (density classes C and D) in which this difference was reduced to less than 10 g/L (Table 1). Instead, a more irregular behaviour was observed for the 'Crimson Seedless' berries, where the differences were ~5 and 35 g/L between density classes C-D and E-F, respectively. This dissimilar floating response may be attributable to the differences found in the acid composition and berry size. In fact, in addition to reducing sugars, the grape density is primarily associated with malic acid, pH, berry weight and berry volume, which was previously demonstrated by Rolle et al. (2012b). In particular, the highest differences in berry volume were detected for cv. Crimson Seedless between density classes C-D (approximately 25%) and E-F (approximately 27%).

Despite this anomalous behaviour, the use of density sorting permitted the assessment of the real chemical characteristics of the berries at different advanced ripening stages, particularly those primarily correlated with the taste score (Sonego et al., 2002). From a consumer's perspective, the organoleptic quality of table grapes depends primarily on the sugar content, the organic acid composition and the balance between these two factors, and the aroma and colour characteristics (Muñoz-Robredo et al., 2011). Specifically regarding 'Crimson Seedless' grapes, Jayasena and Cameron (2008) used sensory testing to demonstrate that acidity is negatively correlated with the degree of consumer satisfaction

and that the SSC/TA ratio is a better predictor of sensory attributes such as sweetness, sourness and flavour compared to °Brix or acidity alone. For cv. Italia, Parpinello et al. (2013) showed that 80% of the consumers assigned to the same class of preferences berries with up two Brix differences (in the range of 12-26 Brix). However, although factors such as SSC, TA and sugar-acid balance are important quality criteria for table grape consumer acceptance, it is impossible to define a universally valid quality standard because consumer sensitivity varies from country to country as demonstrated by Crisosto and Crisosto (2002) using 'Red Globe' table grapes. These authors reported that Chinese consumers are more sensitive to acidity than to the SSC/TA ratio. Differences in these technological parameters can be attributed to the variety, vineyard practices, environmental conditions of the growing location and ripening stage of the berry. In parallel to the chemical composition, an important known role in the global evaluation of the grape quality is berry consistence/crunchiness. In fact, as demonstrated by Zeppa et al. (1999), each chemical composition found at different ripening stages is associated with a different texture profile of the berry; this aspect is therefore crucial in assessing the ability to directly consume fresh table grapes.

For the two table grape varieties used in this trial, the values of all of the skin physico-mechanical properties showed minor changes during grape ripening. This result is consistent with results from research performed on wine grapes (Río Segade et al., 2011b; Zouid et al., 2010); the skin hardness seems to be less dependent on both SSC and harvest date than on the growing location and climate (Maury et al., 2009; Rolle et al., 2011c; Sato et al., 2000). Although several authors (Sato et al., 1997; Sato and Yamada, 2003) have

described the skin texture properties of table grapes, it is difficult to compare their results due to the different operative conditions used in the tests, in particular the type of probe. If only the data regarding skin hardness acquired with the same method are compared, the lowest F_{sk} values for red table grapes were found in 'Black Magic' grapes (0.329 N), while the highest values (0.585 N) were detected in 'Alphonse Lavallée' (Rolle et al., 2013). In the actual study, at all of the tested ripening stages, 'Red Globe' berries displayed F_{sk} values of approximately 0.5 N. 'Crimson Seedless' berries were characterised by F_{sk} values ranging from 0.417 N to 0.519 N. Similar values were also found in a comparative study on ten Italian white table grape varieties; these values ranged from 0.560 N for 'Delizia del Vaprio' to 0.411 N for 'Sultanina' (Rolle et al., 2011a). Higher skin hardness values were reported by Río Segade et al. (2013) in the white table grape 'Italia', where the berries with SSC of 17.3 °Brix were characterised by an average F_{sk} value of 0.787 N. Generally, skin hardness can be considered an influential parameter in handling injury during harvest, packing, transport and storage (Kök and Çelik, 2004).

As reported for 'Italia' table grapes (Río Segade et al., 2013) and a few wine grapes (Torchio et al., 2010), higher skin thickness (Sp_{sk}) values were found to be associated with richer berries in sugars in the present study. In thick-skinned varieties, the commercial acceptance of the grapes could be quite limited if the thickness is not associated with high skin friability (Cliff et al., 1996). In this sense, and in particular for 'Red Globe' berries, the choice of the ripening stage could be the determinant for berry quality. In fact, 'Red Globe' berries with SSC values higher than 15 °Brix showed Sp_{sk} values higher than 270 μm , which are similar to those noticed for white table grapes, including 'Regina' (266 μm), 'Sublima Seedless' (264 μm) and 'Pizzutello Bianco' (260 μm), and coloured table grapes, such as

‘Perlon’ (305 μm) and ‘Alphonse Lavallée’ (269 μm); all of these grapes are considered to be thick-skinned varieties (Rolle et al., 2011a, 2013).

As observed in wine grapes, the mechanical variables that more evolve during ripening were the instrumental texture parameters of the whole berry (Río Segade et al., 2011b; Rolle et al., 2012b; Zouid et al., 2010). Therefore, for both ‘Red Globe’ and ‘Crimson Seedless’, each of the tested ripening stage corresponded to a different texture profile. Although the influence of the pulp and skin properties on the berry mechanical characteristics is aggregated during a compression test, grape softening during ripening could result from significant changes in the cell-wall composition, which is particularly notable at level of the pulp cells (Vargas et al., 2001). These changes continue throughout the postharvest period, and the decrease in berry consistency can be favourably evaluated by TPA parameters such as hardness, cohesiveness, springiness and chewiness (Deng et al., 2005). However, as observed in this study for ‘Crimson Seedless’ berries, the cohesiveness can be considered as one of the best instrumental texture parameters for monitoring the ripening and storage processes because the changes were evident independently of the berry size. The usefulness of berry cohesiveness as a ripeness predictor has been verified for wine grapes (Río Segade et al., 2011b).

Some sensory descriptors can be evaluated by instrumental texture measurements and, in many instances, good relationships with the TPA variables were observed in wine grapes (Le Moigne et al., 2008; Maury et al., 2009). In particular, berry cohesiveness is inversely correlated with sensory quality descriptors, such as elasticity, touch resistance and firmness. The average values of cohesiveness for cvs. Red Globe and Crimson Seedless

berries were 0.58 and 0.52, respectively, which were higher than those reported for different coloured table grape varieties, such as Kyoho (0.275), Black Magic (0.359), Perlou (0.505) and Cardinal (0.507) (Deng et al., 2005; Rolle et al., 2013). Values greater than 0.600 were only reported for the Alphonse Lavallée and Regina Nera varieties (Rolle et al., 2013). The cohesiveness of white table grapes also varied around the values found for 'Red Globe' and 'Crimson Seedless' berries; the values varied from 0.499 to 0.617 (Rolle et al., 2011a).

To the best of our knowledge, very few scientific works have reported data on the pedicel detachment resistance of table grapes. Mattheou et al. (1995) reported a survey of 41 table grape varieties in which the peduncle detachment force ranged from values less than 300 g in seedless and early ripening cultivars to values higher than 500 g in the last maturing seeded cultivars. Generally, this mechanical characteristic is not considered critical for the postharvest preservation of table grapes; however, a higher pedicel detachment facility could cause irreversible berry damage. The peduncle detachment force decreases during cold storage; the value in the Kyoho cultivar halved after 60 days (Deng et al., 2005). This aspect could be relevant only for 'Crimson Seedless' berries with SSC higher than 18.6 °Brix, for which F_{ped} values lower than 3.34 N were observed at harvest.

Conclusions

The physico-mechanical characteristics of 'Red Globe' and 'Crimson Seedless' table grapes were defined in this study. With specific respect to 'Crimson Seedless', the instrumental texture variables pattern showed that the ripening stage was an important

factor affecting the mechanical parameters of the pedicel and whole berry. Therefore, at harvest, knowledge of the berry texture characteristics associated with the corresponding chemical composition can be of great interest in the global evaluation of the grape quality. A relationship between berry size and SSC content was observed only in 'Crimson Seedless'. Because significant relationships for all texture profile analysis parameters and berry size were found, the data for this variety required normalisation. After this data treatment, berry cohesiveness was proposed as a ripeness predictor for table grapes because the changes during ripening were evident independently of berry size.

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Table 1

Technological parameters at different ripening stages of 'Red Globe' and 'Crimson Seedless' table grapes.

Cultivar	Ripening stage	SSC (°Brix)	pH	TA (g/L as tartaric acid)	SSC/TA ratio	Glucose/ Fructose ratio	Citric acid (g/L)	Tartaric acid (g/L)	Malic acid (g/L)	Berry volume (cm ³)
Red Globe	A	12.9±0.1a	3.65±0.05a	6.30±0.21b	20.1±1.2a	0.87±0.05	0.41±0.2 5	3.76±0.21b	1.79±0.08b	10.36±1.50
	B	15.1±0.1b	3.75±0.04a	5.94±0.08b	24.9±0.7b	0.87±0.00	0.30±0.1 1	3.64±0.04b	1.19±0.18a	11.17±1.52
	C	16.9±0.3c	3.93±0.03b	5.31±0.08a	31.7±1.1c	0.92±0.00	0.28±0.0 3	2.87±0.17a	1.22±0.06ab	11.19±1.27
	D	17.6±0.1d	4.02±0.01b	5.06±0.11a	34.2±0.6c	0.93±0.01	0.37±0.1 1	2.98±0.09a	1.54±0.06ab	10.54±1.88
<i>Significance^a</i>		***	**	**	***	ns	ns	**	*	ns
Crimson Seedless	B	14.8±0.2a	3.63±0.04	11.94±0.24c	10.7±0.5a	0.97±0.03	0.41±0.1 5	5.14±0.10c	2.24±0.25b	5.55±0.57c
	C	17.2±0.1b	3.69±0.01	8.55±0.32b	17.4±0.7b	1.00±0.01	0.38±0.0 4	4.61±0.25bc	1.97±0.10ab	5.28±0.89c
	D	17.4±0.1b	3.66±0.02	8.27±0.13ab	18.5±0.4b	0.98±0.01	0.34±0.0 1	4.39±0.11ab	1.74±0.18ab	3.96±0.62b
	E	18.6±0.2c	3.69±0.02	8.78±0.05b	19.4±0.2b	1.01±0.02	0.30±0.1 0	4.75±0.12bc	1.93±0.12ab	3.50±0.67b
	F	21.4±0.5d	3.65±0.08	7.59±0.34a	27.3±1.8c	0.99±0.03	0.32±0.0 3	3.91±0.29a	1.55±0.13a	2.57±0.41a
<i>Significance^a</i>		***	ns	***	***	ns	ns	*	*	***

All data are expressed as average value ± standard deviation. n = 3 (n = 30 for berry volume). Different Latin letters within the same column indicate significant differences (^a) among density classes (Tukey-b test; p < 0.05). Significance^a: *, **, *** and ns indicate significance at p < 0.05, 0.01, 0.001 and not significant, respectively.

A = 1055 kg/m³, B = 1062 kg/m³, C = 1069 kg/m³, D = 1075 kg/m³, E = 1081 kg/m³, F = 1088 kg/m³. SSC = Total soluble solids concentration, TA = Titratable acidity. SSC/TA ratio calculated expressing SSC in g/L and titratable acidity in g/L of tartaric acids.

Table 2

Mechanical properties of the berry skin of 'Red Globe' and 'Crimson Seedless' table grapes at different ripening stages.

Cultivar	Ripening stage	F _{sk} (N)	W _{sk} (mJ)	E _{sk} (N/mm)	Sp _{sk} (μm)
Red Globe	A	0.501±0.080	0.311±0.071	0.399±0.065	226±80a
	B	0.497±0.130	0.302±0.150	0.432±0.110	270±65ab
	C	0.496±0.103	0.333±0.126	0.376±0.093	313±70b
	D	0.540±0.096	0.402±0.130	0.363±0.046	302±56b
<i>Significance^a</i>		ns	ns	ns	*
Crimson Seedless	B	0.462±0.046	0.259±0.060	0.416±0.073	221±47
	C	0.441±0.119	0.261±0.143	0.381±0.062	222±41
	D	0.417±0.103	0.229±0.095	0.381±0.080	222±43
	E	0.475±0.092	0.308±0.096	0.362±0.079	225±43
	F	0.519±0.118	0.348±0.118	0.380±0.052	243±63
<i>Significance^a</i>		ns	ns	ns	ns

All data are expressed as average value ± standard deviation. n = 30. Different Latin letters within the same column indicate significant differences (^a) among density classes (Tukey-b test; p < 0.05). Significance^a: * and ns indicate significance at p < 0.05 and not significant, respectively.

A = 1055 kg/m³, B = 1062 kg/m³, C = 1069 kg/m³, D = 1075 kg/m³, E = 1081 kg/m³, F = 1088 kg/m³. F_{sk} = Berry skin break force, W_{sk} = Berry skin break energy, E_{sk} = Berry skin resistance to axial deformation, Sp_{sk} = Berry skin thickness.

Table 3

Mechanical properties of whole berry of 'Red Globe' and 'Crimson Seedless' table grapes at different ripening stages.

Cultivar	Ripening stage	Firmness (mm)	Hardness (N)	Cohesiveness	Gumminess (N)	Springiness (mm)	Chewiness (mJ)	Resilience
Red Globe	A	2.10±0.71	16.66±5.45	0.56±0.08ab	9.04±2.03	4.90±0.35	44.06±9.58	0.29±0.05
	B	2.13±0.61	16.42±5.13	0.55±0.07a	8.75±1.99	5.01±0.33	43.66±9.64	0.28±0.04
	C	2.39±0.47	13.72±1.98	0.59±0.05ab	8.00±0.78	5.14±0.25	41.10±4.67	0.30±0.04
	D	2.60±0.48	12.99±1.84	0.62±0.06b	7.99±1.13	5.04±0.38	40.47±7.94	0.32±0.04
<i>Significance^a</i>		ns	ns	*	ns	ns	ns	ns
Crimson Seedless	B	1.32±0.31a	19.71±3.89c	0.50±0.04a	9.87±1.76c	3.54±0.16c	35.05±6.97c	0.26±0.02
	C	1.26±0.31a	20.77±4.62c	0.51±0.03a	10.49±2.26c	3.50±0.20c	36.81±8.55c	0.27±0.01
	D	1.43±0.31a	15.48±3.71b	0.52±0.04ab	7.91±1.73b	3.22±0.22b	25.60±6.20b	0.27±0.02
	E	1.60±0.22b	12.40±2.19ab	0.51±0.03ab	6.32±0.92a	3.08±0.23ab	19.52±3.35a	0.27±0.02
	F	1.92±0.64b	9.59±2.90a	0.55±0.08b	5.15±1.26a	3.00±0.14a	15.51±4.12a	0.29±0.05
<i>Significance^a</i>		***	***	*	***	***	***	ns

All data are expressed as average value ± standard deviation. n = 30. Different Latin letters within the same column indicate significant differences (^a) among density classes (Tukey-b test; p < 0.05). Significance^a: *,*** and ns indicate significance at p < 0.05, 0.001 and not significant, respectively.

A = 1055 kg/m³, B = 1062 kg/m³, C = 1069 kg/m³, D = 1075 kg/m³, E = 1081 kg/m³, F = 1088 kg/m³.

Table 4

Mechanical properties of whole berry normalized by berry size (volume as cm^3) for 'Crimson Seedless' table grapes at different ripening stages.

Cultivar	Ripening stage	Firmness (mm/cm^3)	Hardness (N/cm^3)	Cohesiveness ($1/\text{cm}^3$)	Gumminess (N/cm^3)	Springiness (mm/cm^3)	Chewiness (mJ/cm^3)	Resilience ($1/\text{cm}^3$)
Crimson Seedless	B	$0.24 \pm 0.07\text{a}$	3.55 ± 0.59	$0.09 \pm 0.01\text{a}$	1.78 ± 0.27	$0.64 \pm 0.06\text{a}$	$6.31 \pm 1.03\text{ab}$	$0.05 \pm 0.01\text{a}$
	C	$0.25 \pm 0.08\text{a}$	3.98 ± 0.88	$0.10 \pm 0.02\text{a}$	2.02 ± 0.48	$0.68 \pm 0.09\text{a}$	$7.05 \pm 1.66\text{b}$	$0.05 \pm 0.01\text{a}$
	D	$0.37 \pm 0.13\text{ab}$	3.93 ± 0.84	$0.13 \pm 0.03\text{b}$	2.01 ± 0.37	$0.83 \pm 0.12\text{b}$	$6.45 \pm 1.09\text{ab}$	$0.07 \pm 0.01\text{b}$
	E	$0.48 \pm 0.13\text{b}$	3.61 ± 0.67	$0.15 \pm 0.03\text{b}$	1.84 ± 0.33	$0.90 \pm 0.12\text{b}$	$5.63 \pm 0.72\text{a}$	$0.08 \pm 0.02\text{b}$
	F	$0.78 \pm 0.36\text{c}$	3.69 ± 0.91	$0.22 \pm 0.06\text{c}$	2.00 ± 0.42	$1.19 \pm 0.15\text{c}$	$6.00 \pm 1.30\text{ab}$	$0.12 \pm 0.04\text{c}$
<i>Significance^a</i>		***	ns	***	ns	***	*	***

All data are expressed as average value \pm standard deviation. $n = 30$. Different Latin letters within the same column indicate significant differences (^a) among density classes (Tukey-b test; $p < 0.05$). Significance^a: *,*** and ns indicate significance at $p < 0.05$, 0.001 and not significant, respectively.

B = $1062 \text{ kg}/\text{m}^3$, C = $1069 \text{ kg}/\text{m}^3$, D = $1075 \text{ kg}/\text{m}^3$, E = $1081 \text{ kg}/\text{m}^3$, F = $1088 \text{ kg}/\text{m}^3$.

Table 5

Peduncle detachment resistance of ‘Red Globe’ and ‘Crimson Seedless’ table grapes at different ripening stages.

Cultivar	Ripening stage	F _{ped} (N)	W _{ped} (mJ)
Red Globe	A	7.28±1.44b	8.02±2.96
	B	7.66±2.32b	9.30±6.55
	C	7.10±2.14b	8.47±5.26
	D	4.90±1.26a	4.73±3.22
<i>Significance^a</i>		***	ns
Crimson Seedless	B	9.98±3.01c	9.85±4.95b
	C	8.63±2.44c	7.76±2.77b
	D	5.59±1.64b	3.95±1.34a
	E	3.34±1.60ab	2.27±1.95a
	F	2.58±1.17a	1.86±1.14a
<i>Significance^a</i>		***	***

All data are expressed as average value ± standard deviation. n = 30. Different Latin letters within the same column indicate significant differences (^a) among density classes (Tukey-b test; p < 0.05). Significance^a: *** and ns indicate significance at p < 0.001 and not significant, respectively.

A = 1055 kg/m³, B = 1062 kg/m³, C = 1069 kg/m³, D = 1075 kg/m³, E = 1081 kg/m³, F = 1088 kg/m³. F_{ped} = Peduncle detachment force, W_{ped} = Peduncle detachment energy.