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Assessment of sensory firmness and crunchiness of table grapes by acoustic and mechanical properties

Running title: Table grape crunchiness by instrumental properties

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Abstract

Background and Aims: The instrumental measurement of crunchiness in table grapes has been the subject of little research in spite of the great relevance of this sensory texture trait for consumer preferences. Therefore, our aim was to evaluate the potential of several mechanical and acoustic properties to assess the perceived firmness and crunchiness of table grape cultivars.

Methods and Results: The ripening effect was minimised by densimetric sorting of the berries before testing. The textural quality of seven table grape cultivars was evaluated by sensory analysis. Furthermore, three mechanical tests (texture profile analysis, cutting and denture) were performed on the berry flesh or whole berries, and the acoustic emission produced was recorded simultaneously. Correlation studies showed strong and significant relationships between sensory texture attributes and instrumental parameters, particularly for the denture test. Nevertheless, satisfactory predictive accuracy for the perceived crunchiness required multivariate linear regression involving both mechanical and acoustic properties resulting from the denture test performed on whole berries. In this case, residual predictive interquartile amplitude (RPIQ) was higher than 2. Most of the reliable models developed for the perceived firmness are fairly recommended not for quantitative purposes but for fast screening (1.6<RPIQ<2).

Conclusions: The standardised protocol proposed permits to obtain more objective and quantitative sensory data for firmness and crunchiness of table grapes.

Significance of the Study: A combined mechanic-acoustic strategy was not previously used in table grapes and represents a powerful tool for a more complete and exhaustive texture characterisation, particularly firmness and crunchiness, by means of a more objective and standardised protocol.

Keywords: *acoustic emission, crunchiness, instrumental texture analysis, sensory analysis, table grapes*

Introduction

The significant world consumption of table grapes attracts market interest, and the production of cultivars with sensory characteristics greatly appreciated by consumers is a primary objective for grape breeding programs. Texture attributes play a key role in perceived quality and overall acceptability of fresh fruits (Fillion and Kilcast 2002, Konopacka and Plocharski 2004, Péneau et al. 2006, Ha et al. 2007). According to consumer preference, crunchiness represents a major sensory quality trait of table grapes, and as a result cultivars with a crisp flesh texture are in demand for table grape breeding (Sato and Yamada 2003, Sato et al. 2006). In fresh fruits, crispness and crunchiness depend on several factors, such as cultivar, ripening stage, environmental variation, cultural practices and sanitary conditions (Sato et al. 2000, 2004, Jayasena and Cameron 2009, Taniwaki et al. 2009, Zdunek et al. 2010a,b, 2011).

Food textural quality is generally evaluated by descriptive sensory analysis. The within-batch variability in sensory attributes and the subjectivity are important limitations, which should be minimised as much as possible to obtain reliable conclusions (Bavay et al. 2013, 2014). Furthermore, the sensory evaluation of crispness and crunchiness is complex, because of the great variability in the definition of descriptors. Chauvin et al. (2008) developed six standard reference scales for selected dry and wet crisp, crunch and crackly foods, as a first step in improving the differentiation among these important textural concepts, in order to obtain more reproducible sensory data. These difficulties, together with the time required for and the high cost of sensory evaluation, have demanded objective and quantitative measurement of the texture characteristics by instrumental analysis methods (Chen and Opara 2013).

Since the texture perceived in the mouth largely depends on the behaviour of the food while fracturing the tissues during mastication, significant effort has been made in the development of instrumental techniques, which attempt to reproduce the mechanical operations of biting or chewing, for the successful assessment of sensory texture attributes. Penetration/puncture and compression tests are widely used to determine quantitatively the mechanical properties of winegrapes and table grapes (Rolle et al. 2012), together with the cutting test (Giacosa et al. 2014). In table grapes, typical mechanical parameters instrumentally measured to define the textural quality of whole berry and pulp are hardness, cohesiveness, gumminess, springiness, chewiness, resilience, firmness, toughness and stiffness, whereas those used to characterise berry skin are hardness, stiffness and thickness (Sato et al. 1997, Deng et al. 2005, Rolle et al. 2011a, 2013, Río Segade et al. 2013a,b, Giacosa et al. 2014).

In recent years, instrumental acoustic methods have attracted growing interest for the investigation of the structural properties of foods (Saeleaw and Schleining 2011). In fact, crispness and crunchiness are sensory attributes that can be instrumentally assessed by the recording of the acoustic emission produced during the fracturing process of food tissues. Until now, most research on the instrumental measurement of crispness has been focused on dry foods, such as cereal flakes, roasted almonds, potato chips and biscuits (Chaunier et al. 2005, Chen et al. 2005, Varela et al. 2006, 2009, Salvador et al. 2009, Saeleaw and Schleining 2011). Nevertheless, the mastication process is different for fresh fruits compared to that of dry foods, and only a few studies have been published on the application of instrumental acoustic methods to characterise the textural quality of apples and pears (Taniwaki et al. 2009, Zdunek et al. 2010a,b, 2011, Costa et al. 2011). These methods are based on the placement of a microphone close to the sample or an acoustic sensor attached to the mechanical device that contacts the sample. On the other hand, combined mechanical and acoustic strategies provide a better and more realistic evaluation of the sensory perceived crispness/crunchiness than either methodology alone, and can bring better understanding of its perception (Chaunier et al. 2005, Varela et al. 2006, 2009, Salvador et al. 2009, Zdunek et al. 2010a,b, 2011, Costa et al. 2011, Saeleaw and Schleining 2011).

The crisp/crunch character of table grapes has been the subject of little research, in spite of its great relevance for acceptance of table grapes by consumers. Only two works, to date, have been published on the application of instrumental texture parameters as indicators of perceived sensory flesh crispness. Sato et al. (1997) used two mechanical properties, which were obtained from the force-deformation curve during a penetration/puncture test performed on a thick flesh section. They defined crisp texture as easily breakable and firm flesh, corresponding instrumentally to a combination of small DFP (deformation at the first major peak, ≤ 2.5 mm) and large MF (maximum force reached before sample breakdown, ≥ 0.9 N). Despite the necessity of using two parameters, the cultivars studied were classified only into two groups (crisp and non-crisp). More recently, Iwatani et al. (2011) successfully classified nine table grape cultivars according to flesh texture into three groups — crisp, non-crisp and intermediate— using the texture index. This index is based on the energy density measured between 10 Hz and 3.2 kHz during destructive acoustic vibrations produced by the probe penetration in thick flesh slices.

The aim of the present work was to evaluate the potential of different instrumental texture properties (mechanical and acoustic) to assess sensory firmness and crunchiness of several table grape cultivars. All the texture tests were performed on densimetrically sorted berries to minimise the possible ripening effect and thus to obtain more robust conclusions. Whole berries (peeled and/or unpeeled) were subjected to three mechanical tests (double compression, cutting and single compression-shear by denture), and the acoustic emission produced during the test was simultaneously recorded. A combined instrumental strategy has not previously been used in table grapes and could be a powerful tool for a more complete and exhaustive texture characterisation. Furthermore, the relationship between instrumental texture parameters and sensory descriptors was studied in order to characterise table grape cultivars according to firmness and crunchiness by means of a more objective and standardised protocol. The influence of berry size was also investigated.

Materials and methods

Grape samples

The study was carried out in 2012 on four red/black (Apiren Roz, Crimson Seedless, Michele Palieri, Red Globe) and three white (Pizzutello Bianco, T5, Patagonia) *Vitis vinifera* L. table grape cultivars. Apiren Roz and Crimson Seedless were seedless cultivars, whereas the remaining cultivars were seeded. All cultivars grew at the same vineyard located in Apulia Region (Foggia province, Southern Italy, 41°27′42″84N 15°33′0″36E, 230 m asl). The vines, grafted onto 140 R rootstock, were planted at 2.4 x 2.4 m and trained to tendone system Puglia type. At winter pruning, the vines were cane-pruned with four canes of 10/12 buds each. All table grape cultivars were collected at the same harvest date and in accordance with the maturity requirements of the OIV resolution VITI 1/2008 (Organisation Internationale de la Vigne et du Vin 2008a). Twenty bunches were randomly sampled from ten plants (two bunches per vine). Once in the laboratory, all the berries from different parts of each cluster (shoulders, middle, and bottom) were sorted according to their density by flotation in saline solutions, ranging from 70 to 160 g/L sodium chloride, which corresponded to densities comprised between 1045 and 1107 kg/m^3 (Rolle et al. 2011b). For each cultivar, the berries belonging to each density class were then weighed. The berries belonging to the density class of

1081 kg/m^3 were used for the texture study, except that the density class of 1057 kg/m^3 was selected for cv. Michele Palieri, which was characterised by low sugar content. Berry size was calculated following the method proposed by Río Segade et al. (2011a) from the measurement, for each single grape berry, of the length between top and bottom sides (L) and the length between both lateral sides at the middle of berry height (l), using a calliper with an accuracy of 0.1 mm. At least a hundred intact sorted grape berries for each cultivar were randomly selected for sensory and instrumental texture measurements. For each cultivar and density class, the remaining berries were used for chemical analysis of the grape must obtained by manual crushing and centrifugation.

Chemical analysis

Total soluble solids (TSS) concentration (°Brix) was measured with an Atago 0–32°Brix temperature compensating refractometer (Atago Corporation, Tokyo, Japan), pH was determined by potentiometry using an InoLab 730 pH meter (WTW, Weilheim, Germany), and titratable acidity (TA) (g/L tartaric acid) was estimated using OIV methods (Organisation Internationale de la Vigne et du Vin 2008b). Reducing sugars (glucose and fructose) and organic acids (citric acid, tartaric acid and malic acid) (g/L) were determined using a 1260 Infinity HPLC system (Agilent Technologies, Santa Clara, CA, USA) equipped with both a refractive index detector (RI) and a diode array detector (DAD) set to 210 nm. The analyses were performed according to the method proposed by Giordano et al. (2009). The data were analysed with the ChemStation software (Agilent Technologies).

Sensory analysis

Tasting took place in a standard sensory analysis chamber (ISO 2007) equipped with individual booths. Noise and distracting stimuli were absent during the tasting session. Fifteen assessors aged from 20 to 60 years, who were recruited from staff members at the University of Turin (Italy) with experience in sensory analysis of foods, participated initially in this study. Four 2-h preliminary training sessions were conducted to standardise criteria among assessors on the textural quality of table grapes (Cliff et al. 1996, Le Moigne et al. 2008, Olarte Mantilla et al. 2012, 2013). In the first session, the assessors defined the sensory attributes and agreed on the need to evaluate separately three berries per cultivar. Firmness was defined as the mechanical resistance exerted by the sample during chewing, crunchiness as the acoustic emission produced during the first chews and juiciness as the perceived release of juice in the mouth space during mastication. In the following three sessions, the assessors evaluated different reference foods characterised as soft and firm [Perle von Csaba and Superior Seedless grapes, Organisation Internationale de la Vigne et du Vin (2009)], not crunchy and crunchy [banana and green pepper, Chauvin et al. (2008)], and gelatinous and juicy [Delaware and Gamay grapes, Olarte Mantilla et al. (2013)] for firmness, crunchiness and juiciness. The final scale for each attribute was also defined during the training sessions by tasting table grape samples. The perceived intensity of five texture attributes (berry firmness, berry crunchiness, flesh firmness, flesh crunchiness and flesh juiciness) was scored using a linear and unstructured scale with a range of 0 (low)–100 (high) points. After the training sessions, the final panel was composed of a group of six trained panelists (2 females and 4 males), who were selected according to the reproducibility of the results and the higher ability to perceive differences in these sensory attributes (ISO 2012). They evaluated the grape samples by triplicate (total number of samples per cultivar was 18). All samples were labeled with a three-digit code and presented in completely randomised order. The results were then converted to the 0–1 point scale corresponding 0 and 1 to the lowest and highest score, respectively. For this purpose, the following ratio was calculated for each sensory attribute and panelist: (score obtained-minimum score)/(maximum score-minimum score).

Instrumental texture analysis

A Universal Testing Machine (UTM) TA.XTplus texture analyser (Stable Micro Systems, Godalming, Surrey, England) equipped with a HDP/90 platform and a 5 kg load cell was used. All data acquisitions were made at 500 points per second, and the mechanical and acoustic properties were calculated from the corresponding curves using the Texture Exponent software package (Stable Micro Systems). Before each test session, the instrument was calibrated for force, distance and acoustic emission.

The mechanical properties of the berry flesh were evaluated by a Texture Profile Analysis (TPA) test. Each one of the 20 whole berries of each cultivar was peeled and then individually compressed in the equatorial position using a 35 mm P/35 flat cylindrical probe (Stable Micro Systems; Figure 1a) under 25% deformation, with a waiting time between the two bites of 2 s and a test speed of 1 mm/s (Río Segade et al. 2011b). From the force-time curve, typical mechanical parameters that define the berry texture characteristics were calculated by the software: hardness (N, as BH), cohesiveness (adimensional, as BCo), gumminess (N, as BG), springiness (mm, as BS), chewiness (mJ, as BCh) and resilience (adimensional, as BR) (Rolle et al. 2011a). The relative standard error was 6.76, 2.14, 6.49, 2.24, 8.00 and 2.65%, respectively. The berry diameter was calculated as the distance between the berry trigger point and the platform base. Typical force-deformation curve of the TPA test performed on grape was reported in a work previously published (Rolle et al. 2012).

The mechanical properties of the flesh were determined by a cutting test with a HDP/BS blade-type probe (Stable Micro Systems; Figure 1b). For each cultivar, 20 whole berries were manually peeled and then individually placed perpendicular to the blade. The test was carried out at 10 mm/s, cutting the peeled berry up to 90% of its minor diameter and acquiring the force-cutting percentage curve (Giacosa et al. 2014). Cutting hardness of the flesh was assessed by the force (N, as F), toughness was estimated by the energy (mJ, as W), whereas stiffness was evaluated by the resistance to the deformation (N/mm, as E), at the first major deformation peak (point 1, first breakdown of the sample), at the maximum penetration peak under 90% deformation (point 2) and at the maximum breakage peak (max). The force corresponds to the flesh resistance to the blade-type probe penetration, whereas the energy needed to break the flesh is represented by the area under the curve. The third variable is defined as the slope of the force-distance curve in the linear section and measures the flesh stiffness. The relative standard error ranged from 8.89 to 12.57%, from 7.87 to 15.73%, and from 5.19 to 12.63% for F, W, and E, respectively.

A third instrumental texture test was carried out on whole berries, peeled and unpeeled, using dentures (adult male jaw) connected to the texture analyser (Figure 1c), which permits a better simulation of the deformation occurring during compression-shear by teeth. In this case, for each cultivar, 40 whole berries (20 peeled and 20 unpeeled) were individually placed in the equatorial position between the upper and lower molar teeth (Figure 1d), and the mechanical properties of the flesh and berry were determined and defined from the force–distance curve as in the cutting test. The relative standard error ranged from 5.90 to 16.52%, from 7.09 to 8.93%, and from 5.43 to 16.59% for F, W, and E, respectively, in peeled berries and ranged from 5.73 to 7.48%, from 5.83 to 9.76%, and from 5.04 to 7.63%, respectively, in unpeeled berries.

The acoustic emission produced during the cutting and dentures tests was measured using an acoustic envelope detector (AED) (Stable Micro Systems; Figure 1c) equipped with a 12.7 mm diameter Brüel & Kjær 4188-A-021 microphone (Nærum, Germany). The microphone was positioned at a 10-mm distance from the sample at an angle of 45º and connected to the texture analyser. The recording of the acoustic emission produced was carried out at an instrumental gain SPL value of 24 dB using a built-in 3.125 KHz high-pass filter. The instrument was calibrated before each measurement session using an acoustic calibrator Brüel & Kjær type 4231 (94 and 114 dB-1000 Hz). The following instrumental acoustic parameters were measured (Torchio et al. 2012): displacement (mm), sound duration (s), acoustic energy (dB × mm, as AE), positive acoustic energy (dB × mm, as positive AE), linear distance (adimensional, as LD), maximum acoustic pressure level (dB), number of acoustic peaks higher than 10 dB (adimensional, as $N_{pk>10\ dB}$), number of acoustic peaks higher than 5 dB (adimensional, as $N_{pk>5\ dB}$), average acoustic pressure level for peaks with threshold higher than 10 dB (dB, as $AV_{pk>10\ dB}$), and average acoustic pressure level for peaks with threshold higher than 5 dB (dB, as $AV_{pk>5\ dB}$). The relative standard error ranged from 1.72 to 2.44%, from 1.64 to 2.31%, from 2.21 to 2.61%, from 5.91 to 7.96%, from 2.94 to 4.40%, from 2.38 to 2.68%, from 7.46 to 11.21%, from 3.83 to 5.16%, from 0.95 to 2.36%, and from 0.61 to 1.60%, respectively.

Statistical analysis

Data were analysed with the SPSS Statistics software package version 19.0 (IBM Corporation, Armonk, NY, USA). The Tukey-b test at $P < 0.05$ was used to establish significant differences by one-way analysis of variance (ANOVA) in sensory and instrumental texture data among table grape cultivars. Pearson's correlation coefficients were calculated to determine significant relationships between sensory descriptors and instrumental texture parameters. The performance of calibration models developed by regression analysis by partial least squares (PLS) with full cross-validation (leave-one-out) was assessed from the correlation coefficient of calibration (regression coefficient, R_c) and the standard error of cross-validation (SECV). The residual predictive deviation (RPD) is the most commonly used statistical index to account for the model reliability (Bellon-Maurel et al. 2010) and was defined as the ratio between the standard deviation (SD) of the sample set and the SECV value. Another index, the residual predictive interquartile amplitude (RPIQ) based on quartiles, was calculated as the ratio of the interquartile amplitude of the population to the SECV value (Bellon-Maurel et al. 2010). The correlation studies were performed and calibration models were developed on three replicates of six/seven berries for each cultivar, resulting in 21 samples (but about 140 determinations for each test).

Results and discussion

The distribution proportion of the berries in different density classes for the seven table grape cultivars studied, at commercial harvest, is shown in Figure 2. The contribution of each density class depended on the cultivar. Cv. Crimson Seedless and T5 showed a similar distribution because three density classes (1081, 1088 and 1094 kg/m^3) grouped more than 80% w/w of the berries, and the most representative density class was 1088 kg/m^3 (32.1 and 46.0% w/w, respectively). This last density class also contributed predominantly in cv. Patagonia (29.2% w/w), but the distribution was more heterogeneous with a relative berry mass of 84.4% distributed in five density classes (1075, 1081, 1088, 1094 and 1100 kg/m^3). In contrast, the most abundant density class for cv. Michele Palieri was 1057 kg/m^3 (42.0% w/w), whereas most of Red Globe berries were preferentially associated with the density class of 1075 kg/m^3 (46.6% w/w). For the last two cultivars, about 94% w/w of the berries were grouped in three density classes (1051, 1057 and 1069 kg/m^3 for Michele Palieri, and 1069, 1075 and 1081 kg/m^3 for Red Globe). Cv. Apiren Roz showed a similar distribution of the berries to Red Globe (80.9% w/w in the three density classes), however, the two most representative density classes were 1069 and 1075 kg/m^3, which accounted for 65.1% w/w of the berries (33.1 and 32.1% w/w, respectively). In cv. Pizzutello Bianco, two density classes (1081 and 1088 kg/m^3) presented the highest relative mass of the berries with a total of 50.6% (26.6 and 23.9% w/w, respectively). In this case, a contribution of 83.8% w/w required the selection of four density classes (1069, 1075, 1081 and 1088 kg/m^3).

Chemical analysis

Table 1 shows the parameters that define the average technological ripeness of table grapes sorted, at commercial harvest, according to the berry density. Those density classes with berry distribution proportion lower than 3% were not considered. In most cases, lighter berries were associated with a higher density value. In table grapes, Giacosa et al. (2014) reported that the berry density is negatively related to the berry mass, although the variation was small. In the present work, particularly for cv. Apiren Roz, Pizzutello Bianco and Patagonia, an increase in the berry mass was found with increasing berry density up to 1069, 1081 and 1100 kg/m^3, respectively. The same behaviour was observed among Italia berries belonging to the density classes of 1062 and 1067 kg/m^3 (Río Segade et al. 2013a).

As expected, the value of TSS increased with increasing berry density. At the same berry density, a difference lower than 20 g/L was found in the concentration of reducing sugars among cultivars because of densimetric sorting. For those cultivars with a difference in the TA value and the concentration of malic acid among density classes, the trend was for these values to decrease when berry density increased. At any berry density, cv. Crimson Seedless had the highest TA, as a consequence of the highest concentration of tartaric and malic acids. Furthermore, the TSS/TA ratio increased regularly with increasing berry density. Instead, the glucose/fructose ratio and the concentration of tartaric and citric acids were not related to the berry density. At a similar sugar concentration, the cultivars showed large differences in the TSS/TA ratio, glucose/fructose ratio, and acid concentration and profile. The change in these chemical parameters with the berry density agreed with those found in previous studies with other table grapes (Río Segade et al. 2013a,b, Giacosa et al. 2014).

According to the OIV resolution VITI 1/2008 (Organisation Internationale de la Vigne et du Vin 2008a), table grapes are considered ripe at a TSS value equal to or higher than 16°Brix, or when the TSS (expressed as g/L) / TA (expressed as g/L tartaric acid) ratio is greater than 20. In the particular case of seedless cultivars, UE Commission Regulation 543/2011 (Commission Implementing Regulation 2011) establishes that the ripeness is achieved at a TSS equal to or greater than 14°Brix. Jayasena and Cameron (2008) reported that the degree of consumer satisfaction for cv. Crimson Seedless is negatively correlated with the acidity, and that the acceptance increases with increasing TSS from 16 to 20°Brix. As reported in Table 1, all table grape cultivars reached the maturity requirements when the berry density was equal to or higher than 1057 kg/m^3.

In-field grape variability, attributable to physical and environmental factors, such as soil, topography and climate, has led to a Gaussian bell-shaped distribution of berries in the different density classes at harvest, as shown in Figure 2. Such heterogeneity had a strong impact on the chemical composition of the berries. With the aim of minimising differences in the grape ripeness grade among cultivars that could affect the texture characteristics of the berries, the density class of 1081 kg/m^3 was selected for all cultivars for subsequent studies, with the exception of cv. Michele Palieri for which the berry density of 1057 kg/m^3 was used as being the most abundant one. This selection was done on the basis of achieving chemical composition that corresponds to that of the unsorted sample.

Sensory analysis

The scores of the sensory texture attributes evaluated by the trained panelists are shown in Table 2. There were significant differences among table grape cultivars in the five attributes evaluated, but the cultivars were differently classified as function of the sensory parameter assessed. The lowest score of all attributes corresponded to cv. Apiren Roz, whereas Patagonia berries were characterised by their significantly juicier flesh. All remaining cultivars showed intermediate scores of flesh juiciness. Three groups were established for berry firmness, and the highest score corresponded to cv. Red Globe, T5 and Crimson Seedless. Higher heterogeneity was observed among cultivars (five groups) when berry crunchiness was evaluated; Crimson Seedless berries were sensory characterised as the crunchiest. Flesh firmness and crunchiness classified the cultivars quite similarly in four and three groups, respectively. The highest score of flesh crunchiness corresponded to cv. Michele Palieri, Crimson Seedless and Red Globe, but that of flesh firmness was related only to the last two cultivars.

The relationship between sensory attributes was also explored showing that the sensory perception of firmness was closely associated with the perceived crunchiness in table grapes ($r \geq 0.790$, $P < 0.001$, data not shown), particularly when peeled berries were tested ($r = 0.927$, $P < 0.001$, data not shown).

Instrumental texture analysis

A significant difference was found in all texture profile analysis (TPA) parameters of the berry flesh among the seven cultivars (Table 3). According to Tukey-b test ($P < 0.05$), springiness (measurement of the ability to recover the initial form) was the most discriminant parameter because the cultivars were classified in five perfectly differentiated groups. Hardness (measurement of the force necessary to attain a given deformation) and gumminess (measurement of the force necessary to disintegrate a semi-solid food until it is ready for swallowing) also classified the cultivars into four well differentiated groups. Cohesiveness (measurement of the strength of the internal bonds making up the body of the product) and resilience (measurement of how well the product fights to regain its original position) established four interrelated groups of cultivars, whereas chewiness (measurement of the energy necessary to chew a solid food until it is ready for swallowing) was able to differentiate perfectly the cultivars into three groups.

The peeled berries of cv. Apiren Roz were significantly less hard, gummy, springy and chewy than the other six cultivars, whereas those of cv. Michele Palieri were significantly harder, gummier, springier and chewier. On the other hand, a significantly lower value of cohesiveness and of resilience was associated with T5 grapes, while the highest value was recorded for Pizzutello Bianco berries. The results obtained were similar to those previously reported for peeled berries of other table grape cultivars (Giacosa et al. 2014) and generally lower than those of whole unpeeled berries (Rolle et al. 2011a, Río Segade et al. 2013b).

The mechanical and acoustic parameters obtained from the cutting test on berry flesh are shown in Table 4. The difference in the texture attributes among the cultivars was significant. According to Tukey-b test ($P < 0.05$), the acoustic traits, such as displacement, sound duration and acoustic energy (AE), were the most differentiating cutting parameters; they classified the cultivars into five completely separated groups. Toughness at the maximum penetration peak under 90% deformation (W_2) and linear distance (LD) also established five groups of cultivars but not as well differentiated. In contrast, toughness at the first major deformation peak and at the maximum breakage peak (W_1 and W_{max}, respectively), stiffness at the maximum penetration peak under 90% deformation (E_2), maximum acoustic pressure level, and average acoustic pressure level for peaks with a threshold higher than 10 dB and 5 dB ($AV_{pk>10\ dB}$ and $AV_{pk>5\ dB}$, respectively) classified the cultivars into only two groups. Hardness at the first major deformation peak and at the maximum penetration peak under 90% deformation (F_1 and F_2, respectively) were able to differentiate three interrelated groups of cultivars. The remaining cutting parameters discriminated the cultivars into four groups, which were also interrelated.

Apiren Roz and Crimson Seedless showed the lowest value for most of the mechanical and acoustic parameters obtained from the cutting test, with the exception of stiffness at the first breakdown of the sample (E_1) for Apiren Roz and Patagonia, E_2 for Apiren Roz, Crimson Seedless and Patagonia, stiffness at the maximum breakage peak (E_{max}) for Apiren Roz and $AV_{pk>10\ dB}$ for Crimson Seedless. The results found for displacement, sound duration, AE, LD and number of acoustic peaks higher than 5 dB ($N_{pk>5\ dB}$) were significantly lower for Apiren Roz berries. On the contrary, the highest values of the cutting parameters were associated with cv. Michele Palieri, with the exception of F_1, W_1, F_2 and E_2 for which Red Globe berries achieved higher values although they were significantly different to the ones corresponding to cv. Michele Palieri only for W_1. Particularly, the parameters W_2, displacement, sound duration and AE were significantly higher for Michele Palieri berries. Furthermore, cv. Michele Palieri had similar values to those of the Red Globe berries for W_{max}, positive AE, maximum acoustic pressure level, $AV_{pk>10\ dB}$ and $AV_{pk>5\ dB}$, as well as to those of cv. T5 for hardness at the maximum breakage peak (F_{max}) and W_{max}. The results obtained for the mechanical properties were of the same order of magnitude as those previously reported for peeled berries of other table grape cultivars (Giacosa et al. 2014).

The mechanical and acoustic data obtained from the denture test on the berry flesh (Table 5) and whole berry (Table 6) indicate that the differences in the texture attributes among the cultivars studied were significant, with the exception of maximum acoustic pressure level and $AV_{pk>10\ dB}$ measured in peeled berries. For the denture test performed on the berry flesh and according to Tukey-b test ($P < 0.05$) (Table 5), the attributes E_1, W_2, F_{max}, W_{max}, E_{max}, LD, displacement, sound duration and AE classified the cultivars studied into five or four groups, which were completely differentiated using the last three parameters. The less discriminating texture attributes were W_1, F_2, E_2 and $AV_{pk>5\ dB}$ because only two groups of cultivars were established. Regarding the denture test conducted on whole berries and according to Tukey-b test ($P < 0.05$) (Table 6), the attributes E_1, F_2, W_2, F_{max}, number of acoustic peaks higher than 10 dB ($N_{pk>10\ dB}$), $AV_{pk>10\ dB}$ and $N_{pk>5\ dB}$ differentiated the cultivars into four interrelated groups, whereas displacement and sound duration were the most discriminating texture attributes by classifying the cultivars in five completely separated groups. The parameters F_1, E_2 and $AV_{pk>5\ dB}$ were able to differentiate only two groups of cultivars. The remaining parameters discriminated the cultivars in three groups.

Cv. Apiren Roz was characterised by the lowest values of all texture attributes measured by denture testing on the berry flesh or whole berry, with the exception of E_2. The cultivars showing the highest values of the mechanical and acoustic properties depended on the attribute measured and the test applied. Cv. Michele Palieri showed significantly higher values of the parameters W_2, displacement, sound duration and AE measured in the berry flesh (Table 5). Furthermore, this last cultivar presented the greatest values of F_1 and E_1, but the results obtained for F_{max}, E_{max}, positive AE and LD, and $N_{pk>10\ dB}$ were similar to those found for Red Globe, Crimson Seedless, T5, and Pizzutello Bianco, respectively. Red Globe berries had the highest values of F_2, E_2 and W_{max}, whereas the largest $N_{pk>5\ dB}$ corresponded to T5 berries. On the other hand, the parameters E_1 and E_{max} achieved significantly higher values for cv. Crimson Seedless when the denture test was performed on whole berries (Table 6). Red Globe berries, however, were characterised by the highest values of the parameters W_1, F_2, W_2 and F_{max}, and Pizzutello Bianco berries presented the greatest value of $N_{pk>10\ dB}$. In whole berries, cv. Michele Palieri also showed the highest values for displacement, sound duration, AE and $N_{pk>5\ dB}$, but they were not significantly different to those obtained for cv. Red Globe.

Finally, T5 and Red Globe berries achieved the highest values of the parameters W_{max}, AE and LD, whereas T5 and Crimson Seedless berries had the highest values for maximum acoustic pressure level and $AV_{pk>10\ dB}$. No published work, to our knowledge, is available on the application of denture tests to table grapes or other fresh fruits.

Correlations between sensory and instrumental texture attributes

Despite the differences between the groups obtained by sensory and instrumental texture analysis of the cultivars studied (Tables 2–6), some similarities were found. Using the TPA test on the peeled berry, cohesiveness (BCo) was better related to the perceived berry firmness, resilience (BR) to berry firmness and hardness (BH) to flesh crunchiness. The E_1 attribute derived from the cutting test on the peeled berry can be considered the best instrumental parameter for classifying table grape cultivars according to sensory flesh crunchiness. With the denture test, positive AE was associated with perceived firmness; maximum acoustic pressure level and $AV_{pk>10\ dB}$ determined in whole berry evaluated better the perceived berry crunchiness; F_{max} and E_{max} measured in the peeled berry, or W_1 and positive AE determined in whole berry were better related to sensory flesh crunchiness; and finally flesh juiciness was better linked to maximum acoustic pressure level measured directly in whole berries.

Given the lack of full agreement between the groups of cultivars established by sensory and instrumental techniques, a correlation study was performed in order to evaluate the existence of significant relationships between sensory descriptors and instrumental parameters using all cultivars simultaneously. Table 7 shows that the most significant and strongest correlations were found for the attributes obtained from the denture tests. The highest coefficients for the perceived berry firmness corresponded to the correlations with $N_{pk>5\ dB}$ determined in the berry flesh and F_1 measured in whole berry ($r \approx 0.67$, $P < 0.001$). The sensory descriptor berry crunchiness was better correlated with E_1, maximum acoustic pressure level and $AV_{pk>10\ dB}$ determined in whole berry (r = 0.750-0.815, $P < 0.001$). Sensory flesh firmness was highly linked to F_1 determined in whole berry and E_{max} measured in the berry flesh (r = 0.684 and 0.727, respectively, $P < 0.001$). This last instrumental parameter was also highly correlated with the perceived flesh crunchiness (r = 0.774, $P < 0.001$). Flesh juiciness showed the highest correlation factor with maximum acoustic pressure level determined in whole berry (r = 0.573, $P < 0.01$).

Few mechanical-acoustic studies are available on wet-crisp products. The results of the present work with the TPA test were in agreement with those reported by Le Moigne et al. (2008), who demonstrated good correlation between compression parameters and sensory descriptors for winegrapes. Particularly, they found that cohesiveness was negatively correlated with the perception of berry firmness (r = -0.65, $P < 0.05$), whereas no significant correlation was observed for the instrumentally assessed gumminess. Compression with a flat probe imitates chewing with the back molars. Furthermore, as occurred in a series of biscuit-like model foods, the best correlation with sensory crunchiness of the berry flesh corresponded to instrumental hardness, although the coefficients were higher in biscuits (Kim et al. 2012).

Salvador et al. (2009) found that some mechanical properties, such as the area under the force-displacement curve (energy, W) and the slope of the curve up to the first major peak (resistance to deformation, E), were positively correlated to sensory crispness in potato chips. Saklar et al. (1999) also showed a strong negative correlation (r = 0.71-0.96, $P < 0.001$, except for W_2) of sensory crispness and crunchiness in roasted hazelnuts with F, W and E at the two fracture points during a compression test. In fruits, Zdunek et al. (2010a) demonstrated that there is a significant correlation of F_{max} with sensory crispness (r = 0.584, $P < 0.01$), crunchiness (r = 0.539, $P < 0.01$), hardness (r = 0.635, $P < 0.01$), juiciness (r = 0.387, $P < 0.01$) and overall apple texture (r = 0.510, $P < 0.01$) using a puncture test. This agreed with the strong correlation observed in the present work (r = 0.595, $P < 0.01$-0.774, $P < 0.001$) between the perceived flesh crunchiness of table grapes and E_1 using the cutting test performed on the peeled berry, sensory flesh crunchiness and F_1, E_1, F_{max} or E_{max} for the denture test on the peeled berry, the perception of berry crunchiness and F_1, E_1, F_{max} or E_{max} using the denture test on whole berry. Nevertheless, in the present work, energy was not a good marker of sensory crunchiness for table grapes (r < 0.56, $P > 0.001$). Flesh juiciness was also positively related to the mechanical properties F_1 and E_1 using the denture test on whole berries (r = 0.500 and 0.526, respectively, $P < 0.05$).

Several efforts have been made to determine quantitatively flesh firmness of table grapes from the instrumental measurement of mechanical variables. Sato et al. (1997) used the maximum force reached before sample breakdown, which was obtained from the force-deformation curve during a penetration/puncture test performed on a thick flesh section, as an indicator of the sensory perceived flesh firmness (r = 0.84). Similarly, Vargas et al. (2001) demonstrated that the gradient or elasticity coefficient (as E) can be considered a good flesh firmness index by puncture testing on intact whole berry. Likewise in the present work, sensory flesh firmness was better correlated with the mechanical parameters F_{max} and E_{max} obtained from the denture test conducted on the berry flesh (r = 0.629, $P < 0.01$ and 0.727, $P < 0.001$, respectively) or F_1 determined on whole berry (r = 0.684, $P < 0.001$).

Some researchers (Chen et al. 2005, Varela et al. 2006, Salvador et al. 2009) have reported a good correspondence between the sensory assessment of crispness and the number of sound events or maximum acoustic pressure level, which were positively related in biscuits, roasted almonds and potato chips. Crispier/crunchier foods produce a larger number of acoustic peaks (Zdunek et al. 2010a,b, Saeleaw and Schleining 2011). In fact, Zdunek et al. (2010a) found a significant correlation of total acoustic emission counts with sensory crispness (r = 0.670, $P < 0.01$), crunchiness (r= 0.631, $P < 0.01$), hardness (r = 0.659, $P < 0.01$), juiciness (r = 0.511, $P < 0.01$) and overall apple texture (r = 0.618, $P < 0.01$) during a puncture test. In the present work, the number of acoustic peaks (N_{pk}) was not an appropriate index of crunchiness for table grapes (r < 0.49), whereas maximum acoustic pressure level may be particularly useful for predicting sensory berry crunchiness from the denture test on whole berry (r = 0.763, $P < 0.001$). Another commonly used instrumental descriptor of the perceived crunchiness is the average amplitude of acoustic events, which also increases with increasing crunchiness (Chaunier et al. 2005, Zdunek et al. 2010b). Chaunier et al. (2005) reported a linear determination coefficient (r^2) of 0.63 ($P = 0.0012$) in cornflakes using a compression test. Nevertheless, this last parameter depends on the stress level in the source of acoustic emission and on the attenuation of the elastic waves from the source to the sensor. In fact, the hardening of the tissue causes the decrease in the attenuation of the elastic waves (Zdunek et al. 2010b). According to Table 7, the acoustic parameter $AV_{pk>10\ dB}$ determined by the denture test in whole berries could be successfully used as an instrumental indicator of sensory berry crunchiness for table grapes (r = 0.815, $P < 0.001$).

The significance of the mechanical and acoustic attributes suggests a combined methodology wherever possible to predict sensory texture descriptors in table grapes. For this, the relationships between sensory and instrumental data for firmness, crunchiness and juiciness were modelled using PLS, predicting one single sensory attribute at a time. The performance statistics of PLS calibration models are summarised in Table 8. The goodness of the prediction ability requires maximising the regression coefficient of calibration ($R_c > 0.83$), and minimising the_standard error of cross-validation (SECV < 0.26). These assumptions were met for the prediction of the perceived flesh firmness and crunchiness using the TPA test performed on the peeled berry, and for berry firmness, berry crunchiness and flesh juiciness using the denture test on whole berry.

The variation range effect (measurement range or mean of this range) on the SECV value was removed by its standardisation using the residual predictive deviation (RPD) and residual predictive interquartile amplitude (RPIQ) indices (Table 8). Taking into account that a small SECV value if compared to the population spread of a certain attribute gives a relatively high index, the higher the RPD value the greater the predictive accuracy. Some authors established standards referring the RPD values higher than 2.0 to satisfactory calibration models for prediction purposes, whereas the values ranging between 1.4 and 2.0 were indicative of fair models (Chang et al. 2001). Nevertheless, some researchers proposed the use of the RPIQ index to evaluate better the predictive ability of the calibration models (Cozzolino et al. 2011). According to this criterion, the calibration model developed for the mechanical and acoustic parameters calculated from the denture test on whole berries was satisfactory for prediction purposes of sensory berry crunchiness (RPIQ = 2.07; Figure 3). The different instrumental parameters obtained from the TPA test on berry flesh cannot predict quantitatively sensory flesh firmness and crunchiness. Those obtained from the denture test conducted on the whole berry also did not allow the quantitative evaluation of sensory berry firmness. In contrast, their predictive accuracy was acceptable for screening (RPIQ = 1.65–1.80). Flesh juiciness cannot be reliably predicted in table grapes from the instrumental texture attributes determined because of a poor performance of the models.

A correlation study between the instrumental texture parameters and berry size (diameter and volume) was carried out for all cultivars together to show the general pattern, and then for each cultivar separately. Most of the instrumental parameters were significantly correlated to berry size and, therefore, the goodness of the relationships between sensory and instrumental texture parameters could depend on berry size (Table 1S). Furthermore, the magnitude of this effect was also influenced by the cultivar, Red Globe being the least affected table grape cultivar by berry size. Springiness was the TPA parameter better correlated with the diameter and volume, and cohesiveness and resilience were those less correlated according to general and individual trends. In contrast, the diameter and volume showed a stronger correlation with the parameters W_2, displacement, sound duration, AE and LD using the cutting and denture tests, whereas the correlation with E_2 and $AV_{pk>10\ dB}$ was low using the cutting test, with F_2, E_2, maximum acoustic pressure level and $AV_{pk>10\ dB}$ using the denture test in the peeled berry and with E_2, E_{max} and $AV_{pk>10\ dB}$ using the denture test in whole berries. It is important to highlight that the instrumental parameters that were strongly correlated with berry crunchiness were poorly dependent on berry size, which agrees with the high predictive accuracy obtained for this sensory trait.

Conclusions

This study proposes an instrumental methodology with a standardised protocol to obtain more objective and quantitative sensory data for firmness and crunchiness of table grapes. Univariate statistical studies showed improved and more significant correlation of sensory attributes with the instrumental texture variables obtained with the tooth-like probe. Multivariate linear regression by partial least squares, however, constituted a more effective tool for the development of calibration models with the aim of predicting sensory firmness and crunchiness from instrumental parameters. A combined strategy based on the simultaneous sound recording during mechanical testing of intact table grapes using the tooth-like probe was required for a satisfactory evaluation of the sensory perceived crunchiness. The predictive accuracy of the perceived firmness was acceptable only for screening in berry flesh using the mechanical properties from texture profile analysis test, or in the whole berry using the mechanical and acoustic attributes measured by the denture test. The studies relating perceived sensations and instrumental properties are of great interest for table grape cultivars because a crisp/crunch flesh texture is particularly preferred for the breeding programs and highly appreciated by consumers.

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Figure 1. Platform, probes and microphone used in texture analysis tests. (a) Flat probe (∅ 35 mm); (b) HDP/BS blade-type probe; (c) dentures and microphone linked to acoustic envelope detector; and (d) view from above the denture and microphone showing the position of a peeled or unpeeled berry on the denture.

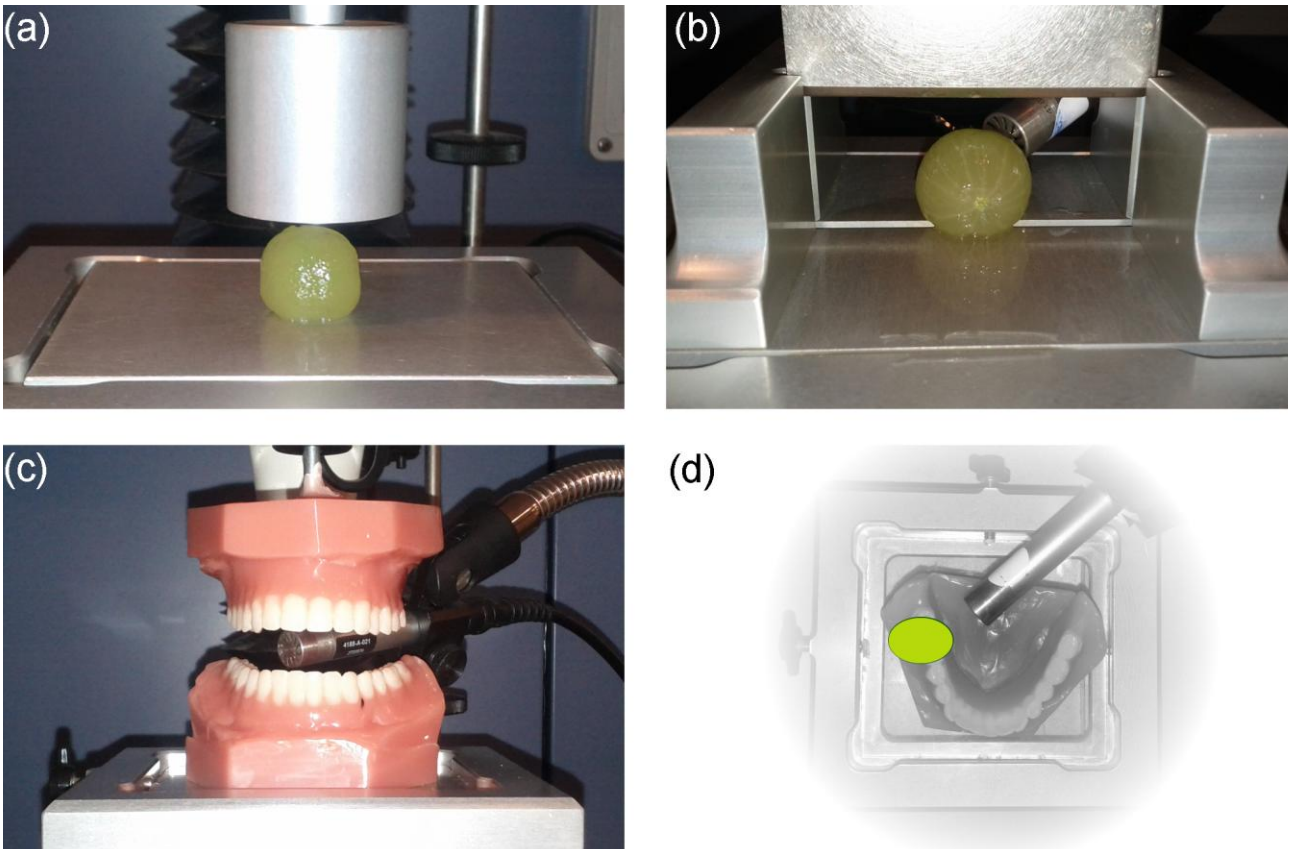

Figure 2. Relative proportion of berries belonging to the density classes studied (1045–1107 kg/m^3) for each cultivar at commercial harvest: 1045 kg/m^3 (■), 1051 kg/m^3 (□), 1057 kg/m^3 (■), 1069 kg/m^3 (■), 1075 kg/m^3 (■), 1081 kg/m^3 (■), 1088 kg/m^3 (■), 1094 kg/m^3 (■), 1100 kg/m^3 (■) and 1107 kg/m^3 (■).

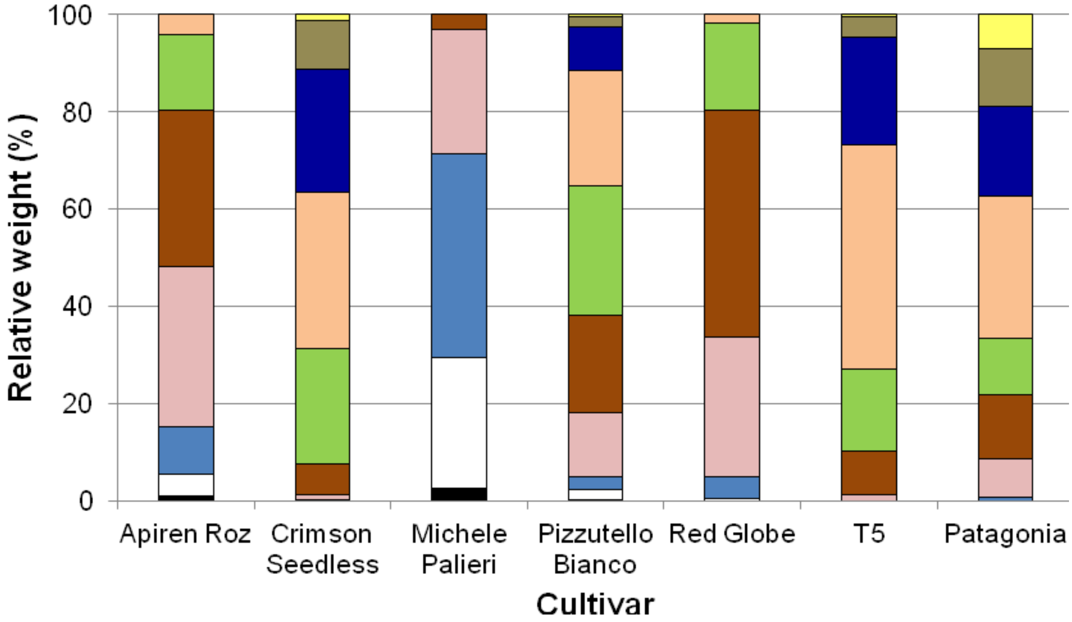

Figure 3. Values predicted instrumentally by whole berry denture test versus sensory scores for berry crunchiness. Calibration (●), validation (●), dashed lines represent confidence intervals at 99% (n = 21).

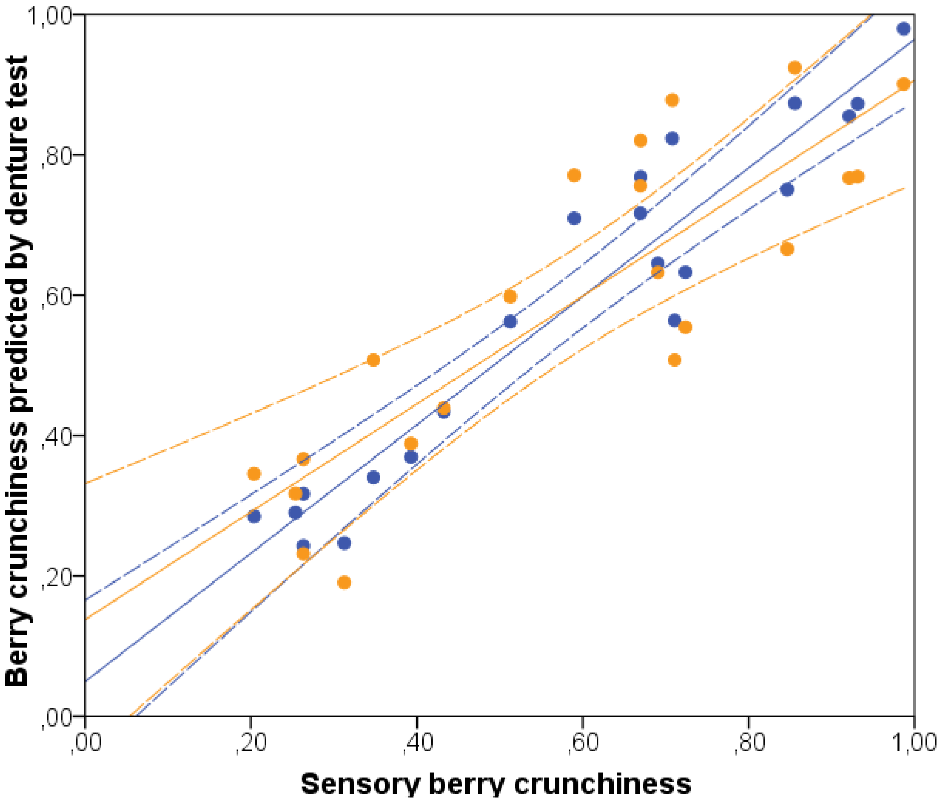

Table 1. Average composition of densimetric sorted berries of seven table grape cultivars at commercial harvest.

Cultivar	Density (kg/m^3)	Berry mass (g)	TSS (ºBrix)	G/F	pH	TA (g/L as tartaric acid)	Tartaric acid (g/L)	Malic acid (g/L)	Citric acid (g/L)	TSS/TA
Apiren Roz	1051	1.93	14.4	0.86	3.50	4.80	6.68	0.79	0.28	30
	1057	2.23	15.9	0.89	3.54	4.76	6.71	0.97	0.32	32
	1069	2.95	16.8	0.85	3.65	4.05	6.09	0.77	0.24	41
	1075	2.44	18.1	0.86	3.62	4.28	6.63	0.88	0.28	42
	1081	2.06	19.2	0.87	3.62	4.24	6.23	0.93	0.31	44
	1088	1.21	20.7	0.92	3.56	4.95	6.91	0.96	0.44	40
Crimson Seedless	1075	3.75	19.5	0.99	3.58	6.53	6.97	3.10	0.43	29
	1081	3.60	21.3	0.98	3.55	6.41	6.89	2.95	0.44	31
	1088	2.94	21.5	0.98	3.52	6.53	7.04	2.95	0.42	32
	1094	2.76	22.6	0.98	3.54	6.38	6.65	3.04	0.44	34
	1100	2.50	24.5	0.99	3.56	6.45	6.60	3.15	0.46	36
Michele Palieri	1051	8.61	14.9	0.94	3.57	5.51	4.64	1.86	0.28	25
	1057	9.04	16.7	0.98	3.50	6.08	4.63	0.00	0.28	26
	1069	8.53	18.6	0.97	3.77	3.60	4.68	2.18	0.24	51
	1075	5.44	20.9	0.98	3.83	3.71	4.91	2.11	0.21	53
Pizzutello	1069	4.77	16.9	0.98	3.78	4.35	6.29	2.23	0.18	39

Bianco	1075	5.10	18.5	0.98	3.90	4.05	5.70	2.53	0.20	46
	1081	5.67	19.7	0.98	3.95	4.16	5.69	2.43	0.19	47
	1088	5.46	21.2	0.96	4.00	3.11	5.80	2.35	0.17	69
	1094	5.24	23.3	0.96	3.96	3.83	6.19	2.53	0.18	61
Red Globe	1057	8.67	17.0	0.84	3.76	4.61	5.49	2.40	0.52	36
	1069	8.81	17.4	0.85	3.90	4.46	5.69	2.57	0.48	40
	1075	7.88	18.6	0.85	3.77	4.50	5.73	2.33	0.47	41
	1081	5.16	18.6	0.85	3.95	3.30	5.04	1.80	0.35	58
T5	1075	5.21	18.2	0.98	3.71	4.50	5.99	1.93	0.55	39
	1081	5.43	19.3	0.99	3.81	4.46	5.63	2.14	0.63	42
	1088	4.84	20.4	0.98	3.82	4.50	5.62	2.13	0.64	45
	1094	4.39	21.4	0.98	3.84	4.20	5.52	1.90	0.60	51
	1100	3.68	21.6	0.98	3.83	4.13	5.85	1.83	0.53	52
Patagonia	1069	5.93	16.8	0.97	3.82	3.75	5.27	2.09	0.17	46
	1075	5.50	18.3	0.97	3.80	3.83	5.65	1.88	0.18	50
	1081	5.64	19.6	1.00	3.76	3.83	5.34	1.69	0.19	53
	1088	6.62	20.3	1.00	3.72	3.75	5.72	1.43	0.18	55
	1094	7.00	21.9	0.99	3.79	3.68	5.69	1.43	0.17	60
	1100	7.25	23.8	0.99	3.87	3.79	5.95	1.48	0.18	65

	1107	6.23	24.1	0.98	3.87	3.45	6.00	1.34	0.18	74

TSS/TA, TSS (expressed as g/L)/TA (expressed as g/L tartaric acid). TSS, total soluble solids; G/F, glucose/fructose; TA, titratable acidity.

Table 2. Sensory descriptive analysis of densimetric sorted berries of seven table grape cultivars at commercial harvest.

Descriptor	Apiren Roz	Crimson Seedless	Michele Palieri	Pizzutello Bianco	Red Globe	T5	Patagonia	Sign
Berry firmness	0.21±0.25a	0.73±0.29c	0.48±0.32bc	0.43±0.30ab	0.77±0.16c	0.76±0.16c	0.55±0.30bc	***
Berry crunchiness	0.26±0.23a	0.82±0.16e	0.32±0.26ab	0.45±0.28abc	0.56±0.29bcd	0.79±0.19de	0.66±0.25cde	***
Flesh firmness	0.18±0.14a	0.77±0.22d	0.58±0.35cd	0.48±0.27bc	0.73±0.26d	0.56±0.19cd	0.31±0.32ab	***
Flesh crunchiness	0.31±0.26a	0.73±0.22c	0.77±0.23c	0.49±0.28ab	0.72±0.21c	0.55±0.27bc	0.34±0.22ab	***
Flesh juiciness	0.25±0.24a	0.53±0.23b	0.43±0.36ab	0.49±0.27ab	0.48±0.31ab	0.58±0.24b	0.83±0.17c	***

Average value ± standard deviation (n= 18). Different letters within the same row indicate a significant difference among table grape cultivars (Tukey-b test; $P<$ 0.05). Sign: *** indicates significance at $P<$ 0.001.

Table 3. Berry flesh mechanical attributes from the texture profile analysis of densimetric sorted berries of seven table grape cultivars at commercial harvest.

Attribute	**Apiren Roz**	**Crimson Seedless**	**Michele Palieri**	**Pizzutello Bianco**	**Red Globe**	**T5**	**Patagonia**	**Sign**
BH (N)	1.80±0.69a	6.5±1.4c	9.4±3.2d	3.3±1.1b	4.0±1.1b	5.9±1.4c	3.8±1.4b	***
BCo	0.410±0.031cd	0.360±0.023b	0.361±0.037b	0.436±0.058d	0.388±0.030bc	0.311±0.036a	0.390±0.040bc	***
BG (N)	0.72±0.24a	2.34±0.55c	3.5±1.3d	1.40±0.36b	1.55±0.39b	1.80±0.34b	1.49±0.55b	***
BS (mm)	1.50±0.18a	1.85±0.14b	2.78±0.37e	2.20±0.19c	2.51±0.22d	2.10±0.19c	2.18±0.24c	***
BCh (mJ)	1.11±0.47a	4.4±1.3b	10.0±4.8c	3.12±0.95b	3.9±1.2b	3.79±0.94b	3.3±1.5b	***
BR	0.197±0.017cd	0.179±0.013bc	0.185±0.025bc	0.206±0.031d	0.176±0.017b	0.142±0.016a	0.167±0.029b	***

Average value ± standard deviation (n= 20). Different letters within the same row indicate a significant difference among table grape cultivars (Tukey-b test; $P < 0.05$). Sign: *** indicates significance at $P < 0.001$. BH, hardness; BCo, cohesiveness; BG, gumminess; BS, springiness; BCh, chewiness; BR, resilience.

Table 4. Berry flesh mechanical and acoustic attributes from cutting test of densimetric sorted berries of seven table grape cultivars at commercial harvest.

Attribute	Apiren Roz	Crimson Seedless	Michele Palieri	Pizzutello Bianco	Red Globe	T5	Patagonia	Sign
Mechanical attributes								
F_1 (N)	1.39±0.25a	1.46±0.46a	2.5±1.1bc	2.14±0.48ab	3.3±2.4c	2.7±1.2bc	1.92±0.84ab	***
W_1 (mJ)	2.20±0.81a	1.9±1.3a	4.4±3.1a	4.7±2.4a	10±12b	5.7±4.3a	4.8±3.0a	***
E_1 (N/mm)	0.381±0.061a	0.52±0.12bc	0.67±0.16d	0.441±0.097ab	0.50±0.14b	0.61±0.16cd	0.356±0.076a	***
F_2 (N)	1.27±0.63a	1.01±0.19a	3.5±4.9bc	2.2±1.0ab	4.3±2.0c	2.84±0.96abc	2.2±1.3ab	***
W_2 (mJ)	12.9±5.2a	17.7±5.4ab	67±25e	29±11bc	53±16d	54±19d	34±13c	***
E_2 (N/mm)	0.109±0.053a	0.071±0.013a	0.18±0.26ab	0.144±0.067ab	0.25±0.12b	0.161±0.052ab	0.128±0.071a	***
F_{max} (N)	2.07±0.61a	2.03±0.54a	7.5±4.6d	3.7±1.5ab	5.9±2.3cd	6.3±2.0d	4.2±2.6bc	***
W_{max} (mJ)	8.4±5.1a	8.0±4.1a	38±21b	15.6±7.4a	35±14b	29±12b	18±11a	***
E_{max} (N/mm)	0.281±0.061a	0.33±0.16ab	0.62±0.30d	0.40±0.17ab	0.46±0.17bc	0.58±0.14cd	0.39±0.18ab	***
Acoustic attributes								
Displacement (mm)	10.1±1.4a	12.0±1.3b	18.3±2.0e	14.0±1.2c	16.3±1.2d	15.9±1.1d	15.7±1.4d	***
Sound duration (s)	1.01±0.14a	1.20±0.13b	1.83±0.20e	1.40±0.12c	1.63±0.12d	1.59±0.11d	1.57±0.14d	***
AE (dBxmm)	305±44a	368±42b	571±69e	439±43c	511±42d	487±42d	479±46d	***
Positive AE (dBxmm)	22±15a	31.6±8.4ab	58±21d	46±10cd	55±17d	40±13bc	40±12bc	***

LD	574±147a	788±155b	1252±324e	1067±152cd	1200±151de	1025±225c	969±173c	***
Maximum (dB)	47.2±5.8a	44.6±2.0a	55.6±9.5b	46.6±3.1a	54.5±7.1b	48.6±5.5a	47.5±4.6a	***
$N_{pk>10\ dB}$	3.2±2.4a	4.8±3.3ab	12.3±5.1d	9.1±4.4c	10.4±3.5cd	8.6±2.8c	7.2±3.5bc	***
$AV_{pk>10\ dB}$ (dB)	43.2±2.4ab	41.5±1.1a	44.1±2.6b	41.8±1.1ab	44.0±2.8b	42.4±1.8ab	42.0±1.2ab	**
$N_{pk>5\ dB}$	16.3±5.1a	25.1±6.7b	37±10d	33.7±4.8cd	34.1±4.9cd	30.4±8.4bc	29.0±5.7bc	***
$AV_{pk>5\ dB}$ (dB)	37.0±1.3a	36.90±0.65a	38.8±1.3b	37.5±1.1a	38.48±0.92b	37.50±0.84a	37.2±1.0a	***

Average value ± standard deviation (n= 20). Different letters within the same row indicate a significant difference among table grape cultivars (Tukey-b test; P< 0.05). Sign: ** and *** indicate significance at P< 0.01 and 0.001, respectively. F, force; W, energy; E, resistance to deformation. $_1$, at the first major deformation peak; $_2$, at the maximum penetration peak under 90% deformation; $_{max}$, at the maximum breakage peak. AE, acoustic energy; LD, linear distance; $N_{pk>10\ dB}$, number of acoustic peaks higher than 10 dB; $AV_{pk>10\ dB}$, average pressure level for peaks higher than 10 dB; $N_{pk>5\ dB}$, number of acoustic peaks higher than 5 dB; $AV_{pk>5\ dB}$, average pressure level for peaks higher than 5 dB.

Table 5. Berry flesh mechanical and acoustic attributes from denture test of densimetric sorted berries of seven table grape cultivars at commercial harvest.

Attribute	Apiren Roz	Crimson Seedless	Michele Palieri	Pizzutello Bianco	Red Globe	T5	Patagonia	Sign
Mechanical attributes								
F_1 (N)	3.04±0.59a	7.2±1.9bc	8.8±2.3c	5.5±1.4b	6.8±2.3b	7.1±1.8b	6.5±1.8b	***
W_1 (mJ)	9.6±3.0a	25.8±8.6b	38±14b	26.5±9.0b	34±20b	32±13 b	29±10b	***
E_1 (N/mm)	0.455±0.083a	0.92±0.24de	0.98±0.22e	0.55±0.14ab	0.63±0.18bc	0.76±0.16cd	0.65±0.18bc	***
F_2 (N)	2.17±0.65a	2.31±0.69a	3.7±5.7a	3.0±1.1a	8.4±8.2b	5.4±6.7ab	2.8±1.3a	**
W_2 (mJ)	18.9±5.5a	55±18bc	102±20d	46±16b	73±27c	74±24c	67±25c	***
E_2 (N/mm)	0.214±0.059a	0.159±0.051a	0.19±0.30a	0.209±0.076a	0.52±0.53b	0.33±0.40ab	0.159±0.069a	**
F_{max} (N)	3.20±0.66a	7.2±1.9bcd	10.4±3.7d	5.6±1.4ab	10.7±7.2d	9.5±5.5cd	6.6±1.9abc	***
W_{max} (mJ)	12.7±5.7a	27.0±9.3b	50±16 cd	29.0±9.5b	58±26d	49±21cd	38±18bc	***
E_{max} (N/mm)	0.419±0.078a	0.90±0.22d	0.98±0.22d	0.53±0.15ab	0.74±0.46bcd	0.79±0.27cd	0.60±0.17abc	***
Acoustic attributes								
Displacement (mm)	9.3±1.4a	13.3±1.2b	18.3±1.3d	13.2±1.4b	15.2±1.8c	14.9±1.6c	15.8±1.8c	***
Sound duration (s)	0.67±0.10a	0.937±0.077b	1.270±0.085d	0.93±0.10b	1.06±0.12c	1.04±0.11c	1.10±0.12c	***
AE (dBxmm)	295±44a	457±50b	607±47d	439±49b	508±58c	521±71c	522±60c	***
Positive AE (dBxmm)	33.0±8.8a	84±21bc	94±22c	69±12b	84±19bc	103±37c	80±27bc	***

LD	610±106a	1023±79b	1252±140d	1068±137bc	1188±148cd	1228±155d	1171±209cd	***
Maximum (dB)	46.2±5.0	47.6±3.4	52.3±5.8	51.6±5.0	52.7±9.6	49.2±7.1	48.3±6.1	ns
$N_{pk>10\ dB}$	5.1±2.6a	8.3±3.8ab	14.1±4.2c	14.9±5.0c	11.5±5.8bc	8.3±5.6ab	10.2±7.5bc	***
$AV_{pk>10\ dB}$ (dB)	41.9±2.1	43.1±2.3	43.6±1.4	43.6±1.6	44.0±4.1	44.5±6.7	42.2±1.8	ns
$N_{pk>5\ dB}$	21.3±4.9a	37.4±3.7b	43.1±6.8bc	38.4±6.8b	42.8±5.7bc	45.6±6.1c	42±11bc	***
$AV_{pk>5\ dB}$ (dB)	37.7±1.3a	39.1±1.4ab	39.3±1.4b	39.9±1.1b	39.0±1.7ab	39.5±1.7b	38.4±1.2ab	***

Average value ± standard deviation (n= 20). Different letters within the same row indicate a significant difference among table grape cultivars (Tukey-b test; P< 0.05). Sign, significance; **, P<0.01,***, P<0.001, ns, not significant. F, force; W, energy; E, resistance to deformation. $_1$, at the first major deformation peak; $_2$, at the maximum penetration peak under 90% deformation; $_{max}$, at the maximum breakage peak. AE, acoustic energy; LD, linear distance; $N_{pk>10\ dB}$, number of acoustic peaks higher than 10 dB; $AV_{pk>10\ dB}$, average pressure level for peaks higher than 10 dB; $N_{pk>5\ dB}$, number of acoustic peaks higher than 5 dB; $AV_{pk>5\ dB}$, average pressure level for peaks higher than 5 dB.

Table 6. Whole berry mechanical and acoustic attributes from denture test of densimetric sorted berries of seven table grape cultivars at commercial harvest.

Attribute	Apiren Roz	Crimson Seedless	Michele Palieri	Pizzutello Bianco	Red Globe	T5	Patagonia	Sign
Mechanical attributes								
F_1 (N)	5.7±1.7a	21.9±4.2b	17.6±6.9b	19.6±5.1b	22.9±5.4b	18.3±5.2b	19.8±6.3b	***
W_1 (mJ)	14.8±7.6a	74 ±23 b	96±48bc	64 ±20b	108±52c	79 ±38 bc	72±34 b	***
E_1 (N/mm)	1.02±0.28a	2.63±0.51d	1.61±0.51b	2.18±0.50c	1.84±0.34bc	1.95±0.34bc	2.04±0.40bc	***
F_2 (N)	6.5±2.4a	14.2±3.1bc	11.1±3.0ab	17.5±9.8c	23.0±4.9d	19.2±5.3cd	12.0±5.2b	***
W_2 (mJ)	46±15a	195±36b	240±90bc	205 ±47 bc	299±60d	256±54cd	219±66bc	***
E_2 (N/mm)	0.58±0.21a	0.95±0.21b	0.52±0.13a	1.07±0.64b	1.15±0.27b	1.04±0.30b	0.64±0.28a	***
F_{max} (N)	7.9±2.3a	24.8±5.3cd	18.4±6.2b	25.4±7.4cd	30.1±5.3d	25.0±4.5cd	22.8±6.7bc	***
W_{max} (mJ)	42±15a	122±51b	123±42b	141±49b	241±66c	208 ±52 c	117±62b	***
E_{max} (N/mm)	0.74±0.21a	2.40±0.60c	1.49±0.60b	1.96±0.52b	1.69±0.36b	1.56±0.33b	1.93±0.44b	***
Acoustic attributes								
Displacement (mm)	10.45±0.76a	14.06±0.76b	19.7±2.0e	15.40±0.93c	18.9±1.2e	17.5±1.3d	17.6±1.9d	***
Sound duration (s)	0.746±0.051a	0.986±0.051b	1.36±0.13e	1.075±0.062c	1.311±0.083e	1.214±0.087d	1.22±0.13d	***
AE (dBxmm)	344±28a	534±42b	686±105c	555±48b	654±48c	647±53c	588±80b	***
Positive AE (dBxmm)	51±25a	140±27c	134±63c	123±31bc	124±28bc	158±29c	96±37b	***

LD	733±162a	1277±131b	1449±264bc	1384±191b	1611±293c	1622±190c	1323±265b	***
Maximum (dB)	56±14a	81.6±3.0c	70±14b	78.0±8.3bc	75±10bc	81.5±3.2c	79.6±5.4bc	***
$N_{pk>10\ dB}$	6.1±3.4a	10.3±3.9b	16.8±5.0cd	17.9±4.9d	17.1±6.7cd	13.6±3.9bcd	13.0±1.9bc	***
$AV_{pk>10\ dB}$ (dB)	44.9±4.4a	58.0±7.2cd	49.5±5.9b	52.4±3.3bcd	50.9±5.9bc	59.5±6.3d	53.6±6.1bcd	***
$N_{pk>5\ dB}$	24.8±6.7a	37.3±5.6b	45.6±7.5d	39.1±5.9bc	49.7±9.0d	44.4±4.8cd	38.7±7.1bc	***
$AV_{pk>5\ dB}$ (dB)	39.5±2.8a	44.8±3.3b	42.5±3.4b	45.7±2.8b	42.7±3.6b	45.1±3.0b	42.9±2.8b	***

Average value ± standard deviation (n= 20). Different letters within the same row indicate a significant difference among table grape cultivars (Tukey-b test; P< 0.05). Sign, significance; ***, P<0.001. F, force; W, energy; E, resistance to deformation. $_1$, at the first major deformation peak; $_2$, at the maximum penetration peak under 90% deformation; $_{max}$, at the maximum breakage peak. AE, acoustic energy; LD, linear distance; $N_{pk>10\ dB}$, number of acoustic peaks higher than 10 dB; $AV_{pk>10\ dB}$, average pressure level for peaks higher than 10 dB; $N_{pk>5\ dB}$, number of acoustic peaks higher than 5 dB; $AV_{pk>5\ dB}$, average pressure level for peaks higher than 5 dB.

Table 7. Significant Pearson's correlation coefficients between sensory and instrumental texture attributes for seven table grape cultivars.

Instrumental/Sensory	Berry firmness	Berry crunchiness	Flesh firmness	Flesh crunchiness	Flesh juiciness
Berry flesh TPA test					
BH (N)	ns	ns	ns	0.510*	ns
BCo	-0.512*	ns	ns	ns	ns
BG (N)	ns	ns	ns	0.492*	ns
BCh (mJ)	ns	ns	ns	0.449*	ns
BR	-0.569**	-0.534*	ns	ns	ns
Berry flesh cutting test					
E_1 (N/mm)	ns	ns	0.508*	0.623**	ns
W_2 (mJ)	ns	ns	ns	0.435*	ns
W_{max} (mJ)	ns	ns	ns	0.462*	ns
Positive AE (dBxmm)	ns	ns	ns	0.484*	ns
LD	ns	ns	0.451*	0.474*	ns
$N_{pk>10\ dB}$	ns	ns	ns	0.441*	ns
$N_{pk>5\ dB}$	ns	ns	0.481*	0.481*	ns
$AV_{pk>5\ dB}$ (dB)	ns	ns	ns	0.500*	ns

Berry flesh denture test					
F_1 (N)	0.462^{*}	ns	0.570^{**}	0.603^{**}	ns
W_1 (mJ)	ns	ns	0.438^{*}	0.438^{*}	ns
E_1 (N/mm)	ns	ns	0.567^{**}	0.642^{**}	ns
F_2 (N)	ns	ns	0.442^{*}	ns	ns
W_2 (mJ)	ns	ns	0.436^{*}	0.528^{*}	ns
F_{max} (N)	0.553^{**}	ns	0.629^{**}	0.635^{**}	ns
E_{max} (N/mm)	0.523^{*}	ns	0.727^{***}	0.774^{***}	ns
Displacement (mm)	0.441^{*}	ns	ns	0.441^{*}	ns
Sound duration (s)	0.441^{*}	ns	ns	0.442^{*}	ns
AE (dBxmm)	0.515^{*}	ns	ns	0.475^{*}	ns
Positive AE (dBxmm)	0.644^{**}	0.459^{*}	0.519^{*}	0.486^{*}	ns
LD	0.639^{**}	ns	0.494^{*}	0.462^{*}	0.499^{*}
Maximum (dB)	ns	ns	0.462^{*}	0.504^{*}	ns
$AV_{pk>10\ dB}$ (dB)	0.435^{*}	ns	0.548^{*}	0.478^{*}	ns
$N_{pk>5\ dB}$	0.673^{***}	0.471^{*}	0.509^{*}	0.446^{*}	0.531^{*}
Whole berry denture test					
F_1 (N)	0.667^{***}	0.620^{**}	0.684^{***}	0.503^{*}	0.500^{*}
W_1 (mJ)	0.565^{**}	ns	0.609^{**}	0.557^{**}	ns

E_1 (N/mm)	0.555**	0.750***	0.590**	ns	0.526*
F_2 (N)	0.483*	ns	0.543*	ns	ns
W_2 (mJ)	0.625**	ns	0.580**	0.471*	ns
E_2 (N/mm)	ns	ns	0.469*	ns	ns
F_{max} (N)	0.618**	0.595**	0.613**	ns	ns
W_{max} (mJ)	0.602**	ns	0.555**	ns	ns
E_{max} (N/mm)	0.485*	0.654**	0.536*	ns	0.490*
Displacement (mm)	0.490*	ns	ns	ns	ns
Sound duration (s)	0.490*	ns	ns	ns	ns
AE (dBxmm)	0.538*	ns	0.499*	0.469*	ns
Positive AE (dBxmm)	0.491*	0.463*	0.600**	0.460*	ns
LD	0.582**	ns	0.547*	ns	ns
Maximum (dB)	0.612**	0.763***	0.480*	ns	0.573**
$AV_{pk>10\ dB}$ (dB)	0.610**	0.815***	0.473*	ns	0.521*
$N_{pk>5\ dB}$	0.465*	ns	0.524*	0.456*	ns
$AV_{pk>5\ dB}$ (dB)	0.482*	0.563**	0.434*	ns	ns

n = 21. Sign, significance; *, $P<0.05$, **, $P<0.01$,***, $P<0.001$, ns, not significant. BH, hardness; BCo, cohesiveness; BG, gumminess; BCh, chewiness; BR, resilience. F, force; W, energy; E, resistance to deformation. $_1$, at the first major deformation peak; $_2$, at the maximum penetration peak under 90% deformation; $_{max}$, at the maximum breakage peak. AE, acoustic energy; LD, linear distance; $N_{pk>10\ dB}$, number of acoustic peaks higher than 10 dB; $AV_{pk>10\ dB}$, average pressure level for peaks higher than 10 dB; $N_{pk>5\ dB}$, number of acoustic peaks higher than 5 dB; $AV_{pk>5\ dB}$, average pressure level for peaks higher than 5 dB.

Table 8. Performance of Partial Least Squares models for prediction of sensory texture attributes from instrumental parameters of seven table grape cultivars.

Sensory descriptor	PLS terms	R_c	SECV	RPD	RPIQ
Berry flesh TPA test					
Berry firmness		0.770	0.297	0.84	1.44
Berry crunchiness		0.771	0.292	0.86	1.56
Flesh firmness	6	0.864	0.203	1.10	1.80
Flesh crunchiness		0.834	0.210	1.01	1.65
Flesh juiciness		0.640	0.284	0.73	1.03
Berry flesh cutting test					
Berry firmness		0.625	0.381	0.65	1.13
Berry crunchiness		0.763	0.292	0.86	1.56
Flesh firmness	6	0.700	0.419	0.53	0.87
Flesh crunchiness		0.742	0.381	0.56	0.91
Flesh juiciness		0.718	0.274	0.75	1.07
Berry flesh denture test					
Berry firmness		0.810	0.442	0.56	0.97
Berry crunchiness		0.869	0.372	0.68	1.22
Flesh firmness	9	0.848	0.392	0.57	0.93
Flesh crunchiness		0.828	0.423	0.50	0.82
Flesh juiciness		0.736	0.455	0.45	0.64
Whole berry denture test					
Berry firmness		0.939	0.258	0.96	1.67
Berry crunchiness		0.957	0.220	1.14	2.07
Flesh firmness	9	0.891	0.306	0.73	1.20
Flesh crunchiness		0.856	0.328	0.64	1.05
Flesh juiciness		0.908	0.259	0.79	1.13

n = 21. IQ, interquartile amplitude; PLS, Partial Least Squares; RPD, residual predictive deviation (SD/SECV); SD, standard deviation; R_c, regression coefficient of calibration; RPIQ, residual predictive interquartile amplitude (IQ/SECV); SECV, standard error of cross-validation.

Table 1S. Significant Pearson's correlation coefficients between instrumental texture attributes and berry size for seven table grape cultivars.

Attribute	All cultivars†		Apiren Roz‡		Crimson Seedless‡		Michele Palieri‡		Pizzutello Bianco‡		Red Globe‡		T5‡		Patagonia‡	
	BD	BV	BD	BV	BD	BV	BD	BV	BD	BV	BD	BV	BD	BV	BD	BV
Berry flesh TPA test																
BH (N)	0.645	0.660	***	***	ns	ns	**	*	***	***	ns	ns	**	**	***	***
BCo	-0.401	-0.325	*	**	ns	ns	ns	ns	***	**	ns	ns	ns	ns	ns	ns
BG (N)	0.609	0.639	***	***	ns	ns	*	*	***	***	ns	ns	**	**	**	**
BS (mm)	0.866	0.870	***	***	**	**	***	***	***	***	***	***	***	***	ns	ns
BCh (mJ)	0.656	0.706	***	***	ns	ns	**	*	***	***	*	**	***	***	*	*
BR	-0.381	-0.296	**	**	ns	ns	ns	ns	***	***	ns	ns	ns	ns	ns	ns
Berry flesh cutting test																
F_1 (N)	0.417	0.382	ns	ns	*	*	**	***	ns	ns	ns	ns	ns	ns	ns	ns
W_1 (mJ)	0.299	0.264§	ns	ns	*	*	**	**	ns	ns	ns	ns	ns	ns	ns	ns
E_1 (N/mm)	0.460	0.438	**	**	ns	ns	**	**	ns	ns	ns	ns	ns	ns	ns	ns
F_2 (N)	0.384	0.334	ns	ns	**	**	ns	ns	ns	ns	ns	ns	*	*	ns	ns
W_2 (mJ)	0.833	0.803	***	***	***	***	***	***	*	*	ns	ns	**	**	*	*
E_2 (N/mm)	0.264§	0.211¥	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
F_{max} (N)	0.638	0.596	***	***	***	***	ns	ns	ns	ns	ns	ns	***	***	ns	ns

W_{max} (mJ)	0.711	0.675	***	***	*	**	*	*	ns	ns	ns	ns	***	***	ns	ns
E_{max} (N/mm)	0.463	0.420	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Displacement (mm)	1.000	0.966	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Sound duration (s)	1.000	0.966	***	***	***	***	***	***	***	***	***	***	***	***	***	***
AE (dBxmm)	0.990	0.962	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Positive AE (dBxmm)	0.694	0.694	ns	ns	**	**	**	**	***	***	ns	ns	***	***	ns	ns
LD	0.832	0.818	**	**	***	***	***	***	***	***	ns	ns	***	***	***	***
Maximum (dB)	0.462	0.435	**	**	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$N_{pk>10\ dB}$	0.635	0.611	*	*	**	**	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
$AV_{pk>10\ dB}$ (dB)	0.350	0.298	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$N_{pk>5\ dB}$	0.747	0.739	ns	ns	***	***	***	***	**	**	ns	ns	**	**	***	***
$AV_{pk>5\ dB}$ (dB)	0.447	0.407	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Berry flesh denture test																
F_1 (N)	0.742	0.683	*	ns	**	**	ns	ns	***	***	*	*	**	**	***	***
W_1 (mJ)	0.706	0.664	*	ns	**	**	ns	ns	***	***	***	***	*	*	***	***
E_1 (N/mm)	0.552	0.507	ns	ns	*	*	ns	ns	*	*	ns	ns	*	*	**	**
F_2 (N)	0.198¥	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
W_2 (mJ)	0.912	0.882	***	***	***	***	**	**	***	***	**	**	***	***	***	***
E_2 (N/mm)	-	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

F_{max} (N)	0.539	0.460	*	*	**	**	ns	ns	***	***	ns	ns	ns	ns	***	***
W_{max} (mJ)	0.718	0.656	*	*	***	**	ns	ns	***	***	**	**	*	*	*	*
E_{max} (N/mm)	0.488	0.421	ns	ns	*	*	ns	ns	*	*	ns	ns	ns	ns	*	*
Displacement (mm)	1.000	0.962	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Sound duration (s)	1.000	0.962	***	***	***	***	***	***	***	***	***	***	***	***	***	***
AE (dBxmm)	0.974	0.914	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Positive AE (dBxmm)	0.636	0.534	ns	ns	***	***	ns	ns	**	**	ns	ns	*	*	ns	ns
LD	0.846	0.753	**	**	***	***	*	*	***	***	ns	ns	***	***	ns	ns
Maximum (dB)	-	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$N_{pk>10\ dB}$	0.393	0.427	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns
$AV_{pk>10\ dB}$ (dB)	-	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*
$N_{pk>5\ dB}$	0.750	0.651	*	**	ns	ns	*	*	***	***	ns	ns	***	***	ns	ns
$AV_{pk>5\ dB}$ (dB)	0.189¥	-	**	**	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Whole berry denture test																
F_1 (N)	0.598	0.566	ns	ns	ns	ns	**	**	ns	ns	ns	ns	***	***	ns	ns
W_1 (mJ)	0.706	0.694	ns	ns	ns	ns	**	**	ns	ns	ns	ns	**	**	*	*
E_1 (N/mm)	0.280§	0.241§	ns	ns	ns	ns	**	**	ns	ns	ns	ns	**	**	ns	*
F_2 (N)	0.392	0.297§	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
W_2 (mJ)	0.863	0.820	*	*	**	**	***	***	**	***	*	*	***	***	**	**

E_2 (N/mm)	-	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
F_{max} (N)	0.560	0.492	ns	ns	ns	ns	**	**	ns	ns	ns	ns	ns	ns	ns	ns
W_{max} (mJ)	0.636	0.544	*	*	ns	ns	**	**	ns	ns	*	ns	ns	ns	ns	ns
E_{max} (N/mm)	0.295§	0.272§	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns
Displacement (mm)	1.000	0.975	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Sound duration (s)	1.000	0.975	***	***	***	***	***	***	***	***	***	***	***	***	***	***
AE (dBxmm)	0.947	0.909	*	*	***	***	***	***	***	***	**	**	***	***	***	***
Positive AE (dBxmm)	0.566	0.514	ns	ns	*	*	*	*	ns	ns	ns	ns	ns	ns	ns	ns
LD	0.789	0.714	ns	ns	***	***	*	*	***	***	ns	ns	***	***	ns	ns
Maximum (dB)	0.416	0.352	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns
$N_{pk>10 dB}$	0.626	0.624	ns	ns	***	***	ns	ns	*	*	ns	ns	**	**	ns	ns
$AV_{pk>10 dB}$ (dB)	0.290§	0.220¥	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$N_{pk>5 dB}$	0.749	0.683	ns	ns	ns	ns	ns	ns	*	*	ns	ns	**	*	ns	ns
$AV_{pk>5 dB}$ (dB)	0.324	0.301	ns	*	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns

†n = 140, *P*< 0.001. ‡n = 20. §*P*< 0.01. ¥*P*< 0.05. Sign, significance; *, *P*<0.05, **, *P*<0.01,***, *P*<0.001, ns, not significant. BH, hardness; BCo, cohesiveness; BG, gumminess; BS, springiness; BCh, chewiness; BR, resilience. F, force; W, energy; E, resistance to deformation. $_1$, at the first major deformation peak; $_2$, at the maximum penetration peak under 90% deformation; $_{max}$, at the maximum breakage peak. AE, acoustic energy; LD, linear distance; $N_{pk>10 dB}$, number of acoustic peaks higher than 10 dB; $AV_{pk>10 dB}$, average pressure level for peaks higher than 10 dB; $N_{pk>5 dB}$, number of acoustic peaks higher than 5 dB; $AV_{pk>5 dB}$, average pressure level for peaks higher than 5 dB. BD, berry diameter; BV, berry volume.