

# Assessment of sensory firmness and crunchiness of tablegrapes by acoustic and mechanical properties

S. GIACOSA<sup>1</sup>, G. ZEPPA<sup>1</sup>, A. BAIANO<sup>2</sup>, F. TORCHIO<sup>1</sup>, S. RÍO SEGADÉ<sup>1</sup>, V. GERBI<sup>1</sup> and L. ROLLE<sup>1</sup>

<sup>1</sup> Dipartimento di Scienze Agrarie, Forestali e Alimentari, Università degli Studi di Torino, Grugliasco (TO), Italia

<sup>2</sup> Dipartimento di Scienze Agrarie, degli Alimenti e dell'Ambiente, Università degli Studi di Foggia, Foggia, Italia

Corresponding author: Dr Susana Río Segade, email susana.riosegade@unito.it

## Abstract

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

**Methods and Results:** The ripening effect was minimised by densimetric sorting of the berries before testing. The textural quality of seven tablegrape cultivars was evaluated by sensory analysis. Furthermore, three mechanical tests (texture profile analysis, cutting and denture) were performed on the berry flesh or on 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 was higher than 2. Most of the reliable models developed for perceived firmness are fairly recommended not for quantitative purposes but for fast screening ( $1.6 < \text{residual predictive interquartile amplitude} < 2$ ).

**Conclusions:** The standardised protocol proposed permits more objective and quantitative sensory data to be obtained for firmness and crunchiness of tablegrapes.

**Significance of the Study:** A combined mechanical–acoustic strategy has not previously been used in tablegrapes 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, tablegrape

## Introduction

The significant world consumption of tablegrapes 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 tablegrapes, and as a result, cultivars with a crisp flesh texture are in demand for tablegrape 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).

Because 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 tablegrapes (Rolle et al. 2012), together with the cutting test (Giacosa et al. 2014). In tablegrapes, 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 with 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. In contrast, 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 tablegrapes has been the subject of little research, in spite of its great relevance for acceptance of tablegrapes by consumers. Only two studies 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 deformation at the first major peak ( $\leq 2.5$  mm) and large maximum force reached before sample breakdown ( $\geq 0.9$  N). Despite the necessity of using two parameters, the cultivars studied were classified into only two groups (crisp and non-crisp). More recently, Iwatani et al. (2011) successfully classified nine tablegrape 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 tablegrape 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 tablegrapes 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 tablegrape 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. tablegrape cultivars. Apiren Roz and Crimson Seedless were seedless cultivars, whereas the remaining cultivars were seeded. All cultivars were grown 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 × 2.4 m and trained to the tendone system Puglia type. At winter pruning, the vines were cane pruned with four canes of 10/12 buds each. All tablegrape cultivars were collected at the same harvest date and in accordance with the ripeness requirements of the Organisation Internationale de la Vigne et du Vin (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 bunch (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 density comprised between 1045 and 1107 kg/m<sup>3</sup> (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<sup>3</sup> were used for the texture study, except that the density class of 1057 kg/m<sup>3</sup> was selected for 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 100 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 and a diode array detector 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 (International Organization for Standardization 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

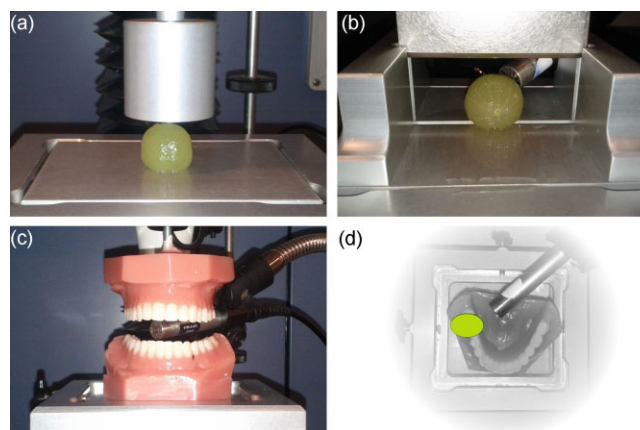
training sessions were conducted to standardise criteria among assessors on the textural quality of tablegrapes (Cliff et al. 1996, Le Moigne et al. 2008, Olarte Mantilla et al. 2012, 2013). In the first session, the assessors defined the sensory attributes and agreed on the need to evaluate separately 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 tablegrape 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 panellists (two females and four males), who were selected according to the reproducibility of the results and the greater ability to perceive differences in these sensory attributes (International Organization for Standardization 2012). They evaluated the grape samples by triplicate (total number of samples per cultivar was 18). All samples were labelled with a three-digit code and presented in completely randomised order. The results were then converted to the 0–1 point scale with 0 and corresponding 1 to the lowest and highest score, respectively. For this purpose, the following ratio was calculated for each sensory attribute and panellist:  $(\text{score obtained} - \text{minimum score}) / (\text{maximum score} - \text{minimum score})$ .

#### Instrumental texture analysis

A Universal Testing Machine TA.XTplus texture analyser (Stable Micro Systems, Godalming, 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 previously published by 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

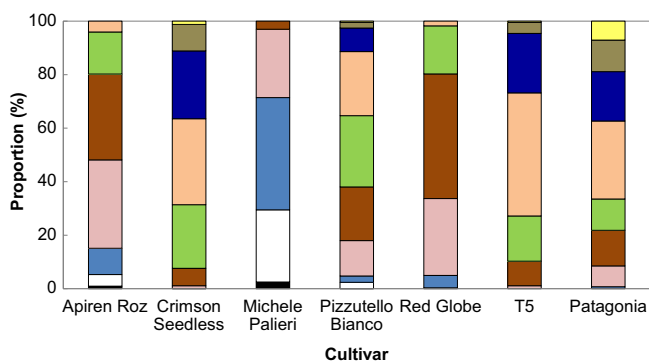


**Figure 1.** Platform, probes and microphone used in texture analysis tests. (a) Flat probe ( $\varnothing$  35 mm); (b) HDP/BS blade-type probe; (c) dentures and microphone linked to acoustic envelope detector; and (d) view from above the denture and microphone showing the position of a peeled or unpeeled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

manually peeled and then placed individually 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 (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 45° and connected to the texture analyser. The recording of the acoustic emission produced was carried out at an instrumental gain 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



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

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  $N_{pk>10\text{ dB}}$ ), number of acoustic peaks higher than 5 dB (adimensional, as  $N_{pk>5\text{ dB}}$ ), average acoustic pressure level for peaks with threshold higher than 10 dB (dB, as  $AV_{pk>10\text{ dB}}$ ) and average acoustic pressure level for peaks with threshold higher than 5 dB (dB, as  $AV_{pk>5\text{ dB}}$ ). 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 in sensory and instrumental texture data among tablegrape 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 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 the different density classes for the seven tablegrape cultivars studied, at commercial harvest, is shown in Figure 2. The contribution of each density

class depended on the cultivar. Crimson Seedless and T5 showed a similar distribution because three density classes (1081, 1088 and 1094 kg/m<sup>3</sup>) grouped more than 80% w/w of the berries, and the most representative density class was 1088 kg/m<sup>3</sup> (32.1 and 46.0% m/m, respectively). This last density class also contributed predominantly in Patagonia (29.2% m/m), 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<sup>3</sup>). In contrast, the most abundant density class for Michele Palieri was 1057 kg/m<sup>3</sup> (42.0% m/m), whereas most of Red Globe berries were preferentially associated with the density class of 1075 kg/m<sup>3</sup> (46.6% m/m). For the last two cultivars, about 94% w/w of the berries were grouped in three density classes (1051, 1057 and 1069 kg/m<sup>3</sup> for Michele Palieri, and 1069, 1075 and 1081 kg/m<sup>3</sup> for Red Globe). Apiren Roz showed a similar distribution of the berries to Red Globe (80.9% m/m in the three density classes); however, the two most representative density classes were 1069 and 1075 kg/m<sup>3</sup>, which accounted for 65.1% m/m of the berries (33.1 and 32.1% w/w, respectively). In Pizzutello Bianco, two density classes (1081 and 1088 kg/m<sup>3</sup>) presented the highest relative mass of the berries with a total of 50.6% (26.6 and 23.9% m/m, respectively). In this case, a contribution of 83.8% m/m required the selection of four density classes (1069, 1075, 1081 and 1088 kg/m<sup>3</sup>).

### Chemical analysis

Table 1 shows the parameters that define the average technological ripeness of tablegrapes sorted, at commercial harvest, according to berry density. Those density classes with a berry distribution proportion lower than 3% were not considered. In most cases, lighter berries were associated with a higher density value. In tablegrapes, 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 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<sup>3</sup>, respectively. The same behaviour was observed among Italia berries belonging to the density classes of 1062 and 1067 kg/m<sup>3</sup> (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, 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 tablegrapes (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), tablegrapes 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, European Commission Regulation 543/2011

**Table 1.** Average composition of densimetric sorted berries of seven tablegrape cultivars at commercial harvest.

Cultivar	Density (kg/m <sup>3</sup> )	Berry mass (g)	TSS (°Brix)	G/F	pH	TA (g/L as tartaric acid)	Tartaric acid (g/L)	Malic acid (g/L)	Citric acid (g/L)	TSS/TA <sup>†</sup>
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 Bianco	1069	4.77	16.9	0.98	3.78	4.35	6.29	2.23	0.18	39
	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

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

(European Commission 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 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 tablegrape cultivars reached the ripeness requirements when the berry density was equal to or higher than 1057 kg/m<sup>3</sup>.

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<sup>3</sup> was selected for all cultivars for subsequent studies, with the exception of Michele Palieri for which the berry density of 1057 kg/m<sup>3</sup> 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 panellists are shown in Table 2. There were significant differences among tablegrape cultivars in the five attributes evaluated, but the cultivars were differently classified as function of the sensory attribute assessed. The lowest score of all attributes corresponded to cv. Apiren Roz, whereas Patagonia

**Table 2.** Sensory descriptive analysis of densimetric sorted berries of seven tablegrape cultivars at commercial harvest.

Attribute	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	***

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

**Table 3.** Berry flesh mechanical attributes from the texture profile analysis of densimetric sorted berries of seven tablegrape 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	***

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

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 Red Globe, T5 and Crimson Seedless. Higher heterogeneity was observed among cultivars (five groups) when berry crunchiness was evaluated: Crimson Seedless berries were 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 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 tablegrapes ( $r \geq 0.790$ ,  $P < 0.001$ , 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 TPA attributes 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 attribute 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 Apiren Roz were significantly less hard, gummy, springy and chewy than that of the other six cultivars, whereas those of Michele Palieri were significantly harder, gummier, springier and chewier. In contrast, 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 tablegrape 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 attributes 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 attributes 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 ( $AV_{pk>10\text{ dB}}$  and  $AV_{pk>5\text{ dB}}$ , 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

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

Attribute	Apiren Roz	Crimson Seedless	Michele Palieri	Pizzutello Bianco	Red Globe	T5	Patagonia	Sign
<b>Mechanical attributes</b>								
F <sub>1</sub> (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 <sub>1</sub> (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 <sub>1</sub> (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 <sub>2</sub> (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 <sub>2</sub> (mJ)	12.9 ± 5.2a	17.7 ± 5.4ab	67 ± 25e	29 ± 11bc	53 ± 16d	54 ± 19d	34 ± 13c	***
E <sub>2</sub> (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 <sub>max</sub> (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 <sub>max</sub> (mJ)	8.4 ± 5.1a	8.0 ± 4.1a	38 ± 21b	15.6 ± 7.4a	35 ± 14b	29 ± 12b	18 ± 11a	***
E <sub>max</sub> (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	***
<b>Acoustic attributes</b>								
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 (dB × mm)	305 ± 44a	368 ± 42b	571 ± 69e	439 ± 43c	511 ± 42d	487 ± 42d	479 ± 46d	***
Positive AE (dB × mm)	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 <sub>pk&gt;10 dB</sub>	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 <sub>pk&gt;10 dB</sub> (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 <sub>pk&gt;5 dB</sub>	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 <sub>pk&gt;5 dB</sub> (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	***

\*\* $P < 0.01$ ; \*\*\* $P < 0.001$ . Average value ± standard deviation ( $n = 20$ ). Different letters within the same row indicate a significant difference among tablegrape cultivars (Tukey-b test;  $P < 0.05$ ). <sub>1</sub>, at the first major deformation peak; <sub>2</sub>, at the maximum penetration peak under 90% deformation; <sub>max</sub>, at the maximum breakage peak; AE, acoustic energy; AV<sub>pk>5 dB</sub>, average pressure level for peaks higher than 5 dB; AV<sub>pk>10 dB</sub>, average pressure level for peaks higher than 10 dB; E, resistance to deformation; F, force; LD, linear distance; N<sub>pk>5 dB</sub>, number of acoustic peaks higher than 5 dB; N<sub>pk>10 dB</sub>, number of acoustic peaks higher than 10 dB; Sign, significance; W, energy.

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 attributes obtained from the cutting test, with the exception of stiffness at the first breakdown of the sample (E<sub>1</sub>) for Apiren Roz and Patagonia, E<sub>2</sub> for Apiren Roz, Crimson Seedless and Patagonia, stiffness at the maximum breakage peak (E<sub>max</sub>) for Apiren Roz and AV<sub>pk>10 dB</sub> for Crimson Seedless. The results found for displacement, sound duration, AE, LD and number of acoustic peaks higher than 5 dB (N<sub>pk>5 dB</sub>) were significantly lower for Apiren Roz berries. On the contrary, the highest values of the cutting parameters were associated with Michele Palieri, with the exception of F<sub>1</sub>, W<sub>1</sub>, F<sub>2</sub> and E<sub>2</sub> for which Red Globe berries achieved higher values although they were significantly different to those corresponding to Michele Palieri only for W<sub>1</sub>. Particularly, the parameters W<sub>2</sub>, displacement, sound duration and AE were significantly higher for Michele Palieri berries. Furthermore, Michele Palieri had similar values to those of the Red Globe berries for W<sub>max</sub>, positive AE, maximum acoustic pressure level, AV<sub>pk>10 dB</sub> and AV<sub>pk>5 dB</sub>, as well as to those of T5 for hardness at the maximum breakage peak (F<sub>max</sub>) and W<sub>max</sub>. The results obtained for the mechanical properties were of the same order of magnitude as those previously reported for peeled berries of other tablegrape 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<sub>pk>10 dB</sub> measured in peeled berries. For the denture test performed on berry flesh and according to Tukey-b test ( $P < 0.05$ ) (Table 5), the attributes E<sub>1</sub>, W<sub>2</sub>, F<sub>max</sub>, W<sub>max</sub>, E<sub>max</sub>, LD, displacement, sound duration and AE classified the cultivars studied into five or four groups, which were completely differentiated using the last three attributes. The less discriminating texture attributes were W<sub>1</sub>, F<sub>2</sub>, E<sub>2</sub> and AV<sub>pk>5 dB</sub> 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<sub>1</sub>, F<sub>2</sub>, W<sub>2</sub>, F<sub>max</sub>, number of acoustic peaks higher than 10 dB (N<sub>pk>10 dB</sub>), AV<sub>pk>10 dB</sub> and N<sub>pk>5 dB</sub> differentiated the cultivars into four interrelated groups, whereas displacement and sound duration were the most discriminating texture attributes by classifying the cultivars into five completely separated groups. The parameters F<sub>1</sub>, E<sub>2</sub> and AV<sub>pk>5 dB</sub> were able to differentiate only two groups of cultivars. The remaining attributes discriminated the cultivars into three groups.

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<sub>2</sub>. The cultivars showing the highest values of the mechanical and acoustic properties depended on the attribute measured and the test applied. Michele Palieri showed significantly higher values of the attributes W<sub>2</sub>, displacement, sound duration and AE measured in the berry flesh (Table 5). Furthermore, this last cultivar presented the highest values of F<sub>1</sub> and E<sub>1</sub>, but the results obtained for F<sub>max</sub>, E<sub>max</sub>, positive AE and LD, and N<sub>pk>10 dB</sub> were similar to those found for Red Globe, Crimson Seedless, T5

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

Attribute	Apiren Roz	Crimson Seedless	Michele Palieri	Pizzutello Bianco	Red Globe	T5	Patagonia	Sign
<b>Mechanical attributes</b>								
F <sub>1</sub> (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 <sub>1</sub> (mJ)	9.6 ± 3.0a	25.8 ± 8.6b	38 ± 14b	26.5 ± 9.0b	34 ± 20b	32 ± 13b	29 ± 10b	***
E <sub>1</sub> (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 <sub>2</sub> (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 <sub>2</sub> (mJ)	18.9 ± 5.5a	55 ± 18bc	102 ± 20d	46 ± 16b	73 ± 27c	74 ± 24c	67 ± 25c	***
E <sub>2</sub> (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 <sub>max</sub> (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 <sub>max</sub> (mJ)	12.7 ± 5.7a	27.0 ± 9.3b	50 ± 16cd	29.0 ± 9.5b	58 ± 26d	49 ± 21cd	38 ± 18bc	***
E <sub>max</sub> (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	***
<b>Acoustic attributes</b>								
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 (dB × mm)	295 ± 44a	457 ± 50b	607 ± 47d	439 ± 49b	508 ± 58c	521 ± 71c	522 ± 60c	***
Positive AE (dB × mm)	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 <sub>pk&gt;10 dB</sub>	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 <sub>pk&gt;5 dB</sub> (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 <sub>pk&gt;5 dB</sub>	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 <sub>pk&gt;5 dB</sub> (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	***

\*\* $P < 0.01$ ; \*\*\* $P < 0.001$ ; ns, not significant. Average value ± standard deviation ( $n = 20$ ). Different letters within the same row indicate a significant difference among tablegrape cultivars (Tukey-b test;  $P < 0.05$ ). <sub>1</sub>, at the first major deformation peak; <sub>2</sub>, at the maximum penetration peak under 90% deformation; <sub>max</sub>, at the maximum breakage peak; AE, acoustic energy; AV<sub>pk>5 dB</sub>, average pressure level for peaks higher than 5 dB; AV<sub>pk>10 dB</sub>, average pressure level for peaks higher than 10 dB; E, resistance to deformation; F, force; LD, linear distance; N<sub>pk>5 dB</sub>, number of acoustic peaks higher than 5 dB; N<sub>pk>10 dB</sub>, number of acoustic peaks higher than 10 dB; Sign, significance; W, energy.

and Pizzutello Bianco, respectively. Red Globe berries had the highest values of F<sub>2</sub>, E<sub>2</sub> and W<sub>max</sub>, whereas the highest N<sub>pk>5 dB</sub> corresponded to T5 berries. In contrast, the attributes E<sub>1</sub> and E<sub>max</sub> achieved significantly higher values for 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 attributes W<sub>1</sub>, F<sub>2</sub>, W<sub>2</sub> and F<sub>max</sub>, and Pizzutello Bianco berries presented the highest value of N<sub>pk>10 dB</sub>. In whole berries, Michele Palieri also showed the highest values for displacement, sound duration, AE and N<sub>pk>5 dB</sub>, but they were not significantly different to those obtained for Red Globe. Finally, T5 and Red Globe berries achieved the highest values of W<sub>max</sub>, AE and LD, whereas T5 and Crimson Seedless berries had the highest values for maximum acoustic pressure level and AV<sub>pk>10 dB</sub>. No published work, to our knowledge, is available on the application of denture tests to tablegrapes 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 perceived berry firmness, resilience (BR) to berry firmness and hardness (BH) to flesh crunchiness. The E<sub>1</sub> attribute derived from the cutting test on the peeled berry can be considered the best instrumental attribute for classifying tablegrape cultivars according to sensory flesh crunchiness. With the denture test, positive AE was associated with perceived firmness; maximum acoustic pressure level and AV<sub>pk>10 dB</sub> determined in whole berry

evaluated better the perceived berry crunchiness; F<sub>max</sub> and E<sub>max</sub> measured in the peeled berry, or W<sub>1</sub> 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 attributes 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<sub>pk>5 dB</sub> determined in the berry flesh and F<sub>1</sub> measured in whole berry ( $r \approx 0.67$ ,  $P < 0.001$ ). The sensory descriptor berry crunchiness was better correlated with E<sub>1</sub>, maximum acoustic pressure level and AV<sub>pk>10 dB</sub> determined in whole berry ( $r = 0.750$ – $0.815$ ,  $P < 0.001$ ). Sensory flesh firmness was tightly linked to F<sub>1</sub> determined in the whole berry and E<sub>max</sub> measured in the berry flesh ( $r = 0.684$  and  $0.727$ , respectively,  $P < 0.001$ ). This last instrumental attribute 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),



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

Attribute	Apiren Roz	Crimson Seedless	Michele Palieri	Pizzutello Bianco	Red Globe	T5	Patagonia	Sign
<b>Mechanical attributes</b>								
F <sub>1</sub> (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 <sub>1</sub> (mJ)	14.8 ± 7.6a	74 ± 23b	96 ± 48bc	64 ± 20b	108 ± 52c	79 ± 38bc	72 ± 34b	***
E <sub>1</sub> (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 <sub>2</sub> (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 <sub>2</sub> (mJ)	46 ± 15a	195 ± 36b	240 ± 90bc	205 ± 47bc	299 ± 60d	256 ± 54cd	219 ± 66bc	***
E <sub>2</sub> (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 <sub>max</sub> (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 <sub>max</sub> (mJ)	42 ± 15a	122 ± 51b	123 ± 42b	141 ± 49b	241 ± 66c	208 ± 52c	117 ± 62b	***
E <sub>max</sub> (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	***
<b>Acoustic attributes</b>								
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 (dB × mm)	344 ± 28a	534 ± 42b	686 ± 105c	555 ± 48b	654 ± 48c	647 ± 53c	588 ± 80b	***
Positive AE (dB × mm)	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 <sub>pk&gt;10 dB</sub>	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 <sub>pk&gt;10 dB</sub> (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 <sub>pk&gt;5 dB</sub>	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 <sub>pk&gt;5 dB</sub> (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	***

\*\*\* $P < 0.001$ . Average value ± standard deviation ( $n = 20$ ). Different letters within the same row indicate a significant difference among tablegrape cultivars (Tukey-b test;  $P < 0.05$ ). 1, at the first major deformation peak; 2, at the maximum penetration peak under 90% deformation; max, at the maximum breakage peak; AV<sub>pk>5 dB</sub>, average pressure level for peaks higher than 5 dB; AV<sub>pk>10 dB</sub>, average pressure level for peaks higher than 10 dB; E, resistance to deformation; F, force; LD, linear distance; AE, acoustic energy; N<sub>pk>5 dB</sub>, number of acoustic peaks higher than 5 dB; N<sub>pk>10 dB</sub>, number of acoustic peaks higher than 10 dB; Sign, significance; W, energy.

who demonstrated good correlation between compression parameters and sensory descriptors for winegrapes. In particular, 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<sub>2</sub>) 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<sub>max</sub> 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 tablegrapes and E<sub>1</sub> using the cutting test performed on the peeled berry, sensory flesh crunchiness and F<sub>1</sub>, E<sub>1</sub>, F<sub>max</sub> or E<sub>max</sub> for the denture test on the peeled berry, the perception of berry crunchiness and F<sub>1</sub>, E<sub>1</sub>, F<sub>max</sub>

or E<sub>max</sub> using the denture test on whole berry. Nevertheless, in the present work, energy was not a good marker of sensory crunchiness for tablegrapes ( $r < 0.56$ ,  $P > 0.001$ ). Flesh juiciness was also positively related to the mechanical properties F<sub>1</sub> and E<sub>1</sub> 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 tablegrapes 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<sub>max</sub> and E<sub>max</sub> 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<sub>1</sub> 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

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

Instrumental/sensory	Berry firmness	Berry crunchiness	Flesh firmness	Flesh crunchiness	Flesh juiciness
<b>Berry flesh TPA test</b>					
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
<b>Berry flesh cutting test</b>					
E <sub>1</sub> (N/mm)	ns	ns	0.508*	0.623**	ns
W <sub>2</sub> (mJ)	ns	ns	ns	0.435*	ns
W <sub>max</sub> (mJ)	ns	ns	ns	0.462*	ns
Positive AE (dB × mm)	ns	ns	ns	0.484*	ns
LD	ns	ns	0.451*	0.474*	ns
N <sub>pk&gt;10 dB</sub>	ns	ns	ns	0.441*	ns
N <sub>pk&gt;5 dB</sub>	ns	ns	0.481*	0.481*	ns
AV <sub>pk&gt;5 dB</sub> (dB)	ns	ns	ns	0.500*	ns
<b>Berry flesh denture test</b>					
F <sub>1</sub> (N)	0.462*	ns	0.570**	0.603**	ns
W <sub>1</sub> (mJ)	ns	ns	0.438*	0.438*	ns
E <sub>1</sub> (N/mm)	ns	ns	0.567**	0.642**	ns
F <sub>2</sub> (N)	ns	ns	0.442*	ns	ns
W <sub>2</sub> (mJ)	ns	ns	0.436*	0.528*	ns
F <sub>max</sub> (N)	0.553**	ns	0.629**	0.635**	ns
E <sub>max</sub> (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 (dB × mm)	0.515*	ns	ns	0.475*	ns
Positive AE (dB × mm)	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 <sub>pk&gt;10 dB</sub> (dB)	0.435*	ns	0.548*	0.478*	ns
N <sub>pk&gt;5 dB</sub>	0.673***	0.471*	0.509*	0.446*	0.531*
<b>Whole berry denture test</b>					
F <sub>1</sub> (N)	0.667***	0.620**	0.684***	0.503*	0.500*
W <sub>1</sub> (mJ)	0.565**	ns	0.609**	0.557**	ns
E <sub>1</sub> (N/mm)	0.555**	0.750***	0.590**	ns	0.526*
F <sub>2</sub> (N)	0.483*	ns	0.543*	ns	ns
W <sub>2</sub> (mJ)	0.625**	ns	0.580**	0.471*	ns
E <sub>2</sub> (N/mm)	ns	ns	0.469*	ns	ns
F <sub>max</sub> (N)	0.618**	0.595**	0.613**	ns	ns
W <sub>max</sub> (mJ)	0.602**	ns	0.555**	ns	ns
E <sub>max</sub> (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 (dB × mm)	0.538*	ns	0.499*	0.469*	ns
Positive AE (dB × mm)	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 <sub>pk&gt;10 dB</sub> (dB)	0.610**	0.815***	0.473*	ns	0.521*
N <sub>pk&gt;5 dB</sub>	0.465*	ns	0.524*	0.456*	ns
AV <sub>pk&gt;5 dB</sub> (dB)	0.482*	0.563**	0.434*	ns	ns

\* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$ ; ns, not significant.  $n = 21$ . <sub>1</sub>, at the first major deformation peak; <sub>2</sub>, at the maximum penetration peak under 90% deformation; <sub>max</sub>, at the maximum breakage peak; AV<sub>pk>5 dB</sub>, average pressure level for peaks higher than 5 dB; AV<sub>pk>10 dB</sub>, average pressure level for peaks higher than 10 dB; BCh, chewiness; BCo, cohesiveness; BG, gumminess; BH, hardness; BR, resilience; F, force; E, resistance to deformation; LD, linear distance; AE, acoustic energy; N<sub>pk>5 dB</sub>, number of acoustic peaks higher than 5 dB; N<sub>pk>10 dB</sub>, number of acoustic peaks higher than 10 dB; Sign, significance; W, energy.

**Table 8.** Performance of partial least squares models for prediction of sensory texture attributes from instrumental attributes of seven tablegrape cultivars.

Sensory descriptor	PLS terms	R <sub>c</sub>	SECV	RPD	RPIQ
<b>Berry flesh TPA test</b>					
Berry firmness	6	0.770	0.297	0.84	1.44
Berry crunchiness		0.771	0.292	0.86	1.56
Flesh firmness		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
<b>Berry flesh cutting test</b>					
Berry firmness	6	0.625	0.381	0.65	1.13
Berry crunchiness		0.763	0.292	0.86	1.56
Flesh firmness		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
<b>Berry flesh denture test</b>					
Berry firmness	9	0.810	0.442	0.56	0.97
Berry crunchiness		0.869	0.372	0.68	1.22
Flesh firmness		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
<b>Whole berry denture test</b>					
Berry firmness	9	0.939	0.258	0.96	1.67
Berry crunchiness		0.957	0.220	1.14	2.07
Flesh firmness		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

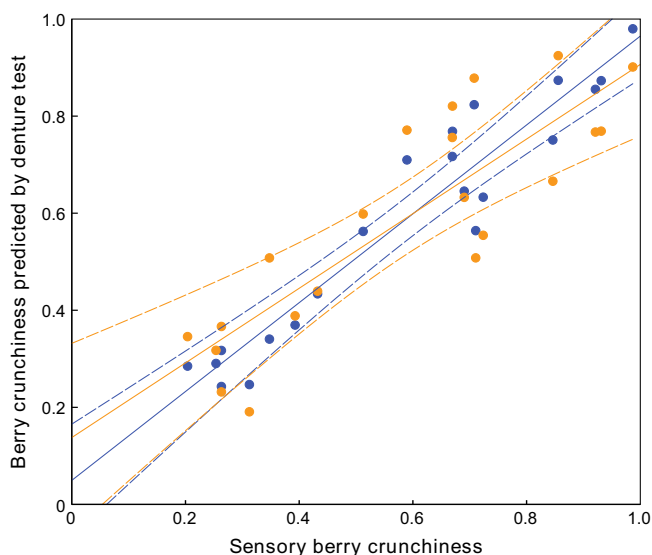
n = 21. IQ, interquartile amplitude; PLS, partial least squares; R<sub>c</sub>, regression coefficient of calibration; RPD, residual predictive deviation (SD/SECV); RPIQ, residual predictive interquartile amplitude (IQ/SECV); SD, standard deviation; SECV, standard error of cross-validation.

( $r = 0.670$ ,  $P < 0.01$ ), 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 tablegrapes ( $r < 0.49$ ), whereas maximum acoustic pressure level may be particularly useful for predicting sensory berry crunchiness from the denture test on the 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  $AV_{pk>10\text{ dB}}$  determined by the denture test in whole berries could be successfully used as an instrumental indicator of sensory berry crunchiness for tablegrapes ( $r = 0.815$ ,  $P < 0.001$ ).

The significance of the mechanical and acoustic attributes suggests a combined methodology wherever possible to predict sensory texture descriptors in tablegrapes. For this, the relation-

ships 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 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 the whole berry.

The variation range effect (measurement range or mean of this range) on the SECV value was removed by its standardisation using the RPD and RPIQ indices (Table 8). Taking into account that a small SECV value if compared with 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



**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% ( $n = 21$ ).

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 tablegrapes 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 S1). Furthermore, the magnitude of this effect was also influenced by the cultivar, Red Globe being the least affected tablegrape 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 attributes  $W_2$ , displacement, sound duration, AE and LD using the cutting and denture tests, whereas the correlation with  $E_2$  and  $AV_{pk>10\text{ dB}}$  was low using the cutting test, with  $F_2$ ,  $E_2$ , maximum acoustic pressure level and  $AV_{pk>10\text{ dB}}$  using the denture test in the peeled berry and with  $E_2$ ,  $E_{\text{max}}$  and  $AV_{pk>10\text{ dB}}$  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 tablegrapes.

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 PLS, 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 tablegrapes 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 TPA 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 tablegrape cultivars because a crisp/crunch flesh texture is particularly preferred for the breeding programs and highly appreciated by consumers.

## References

- Bavay, C., Symoneaux, R., Maître, I., Kuznetsova, A., Brockhoff, P.B. and Mehinagic, E. (2013) Importance of fruit variability in the assessment of apple quality by sensory evaluation. *Postharvest Biology and Technology* **77**, 67–74.
- Bavay, C., Brockhoff, P.B., Kuznetsova, A., Maître, I., Mehinagic, E. and Symoneaux, R. (2014) Consideration of sample heterogeneity and in-depth analysis of individual differences in sensory analysis. *Food Quality and Preference* **32**, 126–131.
- Bellon-Maurel, V., Fernandez-Ahumada, E., Palagos, B., Roger, J.-M. and McBratney, A. (2010) Critical review of chemometric indicators commonly used for assessing the quality of the prediction of soil attributes by NIR spectroscopy. *Trends in Analytical Chemistry* **29**, 1073–1081.
- Chang, C.-W., Laird, D.A., Mausbach, M.J. and Hurburgh, C.R. Jr. (2001) Near-Infrared reflectance spectroscopy-principal components regression analyses of soil properties. *Soil Science Society of America Journal* **65**, 480–490.
- Chaunier, L., Courcoux, P., della Valle, G. and Lourdin, D. (2005) Physical and sensory evaluation of cornflakes crispness. *Journal of Texture Studies* **36**, 93–118.
- Chauvin, M.A., Younce, F., Ross, C. and Swanson, B. (2008) Standard scales for crispness, crackliness and crunchiness in dry and wet foods: relationship with acoustical determinations. *Journal of Texture Studies* **39**, 345–368.
- Chen, J., Karlsson, C. and Povey, M. (2005) Acoustic envelope detector for crispness assessment of biscuits. *Journal of Texture Studies* **36**, 139–156.
- Chen, L. and Opara, U.L. (2013) Approaches to analysis and modeling texture in fresh and processed foods – a review. *Journal of Food Engineering* **119**, 497–507.
- Cliff, M.A., Dever, M.C. and Reynolds, A.G. (1996) Descriptive profiling of new and commercial British Columbia table grape cultivars. *American Journal of Enology and Viticulture* **47**, 301–308.
- Costa, F., Cappellin, L., Longhi, S., Guerra, W., Magnago, P., Porro, D., Soukoulis, C., Salvi, S., Velasco, R., Biasioli, F. and Gasperi, F. (2011) Assessment of apple (*Malus domestica* Borkh.) fruit texture by a combined acoustic-mechanical profiling strategy. *Postharvest Biology and Technology* **61**, 21–28.
- Cozzolino, D., Cynkar, W., Shah, N. and Smith, P. (2011) Quantitative analysis of minerals and electric conductivity of red grape homogenates by near infrared reflectance spectroscopy. *Computers and Electronics in Agriculture* **77**, 81–85.
- Deng, Y., Wu, Y. and Li, Y. (2005) Effects of high  $O_2$  levels on post-harvest quality and shelf life of table grapes during long-term storage. *European Food Research and Technology* **221**, 392–397.
- European Commission (2011) Commission Implementing Regulation (EU) No 543/2011 of 7 June 2011 laying down detailed rules for the application of Council Regulation (EC) No 1234/2007 in respect of the fruit and vegetables and processed fruit and vegetables sectors. *Official Journal of the European Union L* **157**, 1–163.
- Fillion, L. and Kilcast, D. (2002) Consumer perception of crispness and crunchiness in fruits and vegetables. *Food Quality and Preference* **13**, 23–29.
- Giacosa, S., Torchio, F., Río Segade, S., Giust, M., Tomasi, D., Gerbi, V. and Rolle, L. (2014) Selection of a mechanical property for flesh firmness of table grapes in accordance with an OIV ampelographic descriptor. *American Journal of Enology and Viticulture* **65**, 206–214.

- Giordano, M., Rolle, L., Zeppa, G. and Gerbi, V. (2009) Chemical and volatile composition of three Italian sweet white Passito wines. *Journal International des Sciences de la Vigne et du Vin* **43**, 159–170.
- Ha, S.Y., Hwang, Y.S., Yang, Y.J. and Park, Y.M. (2007) Correlation between instrumental quality attributes and consumers' sensory evaluation in refrigerated-stored 'Campbell early' and 'Kyoho' grape. *Korean Journal of Horticultural Science & Technology* **25**, 125–132.
- International Organization for Standardization (2007) ISO:8589. Sensory analysis – general guidance for the design of test rooms (International Organization for Standardization: Geneva, Switzerland).
- International Organization for Standardization (2012) ISO:8586. Sensory analysis – general guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors (International Organization for Standardization: Geneva, Switzerland).
- Iwatani, S.-I., Yakushiji, H., Mitani, N. and Sakurai, N. (2011) Evaluation of grape flesh texture by an acoustic vibration method. *Postharvest Biology and Technology* **62**, 305–309.
- Jayasena, V. and Cameron, I. (2008) °Brix/acid ratio as a predictor of consumer acceptability of Crimson Seedless table grapes. *Journal of Food Quality* **31**, 736–750.
- Jayasena, V. and Cameron, I. (2009) The effect of ethephon and clone on physical characteristics and sensory quality of Crimson Seedless table grapes after 1 month storage. *International Journal of Food Science and Technology* **44**, 409–414.
- Kim, E.H.-J., Corrigan, V.K., Wilson, A.J., Waters, I.R., Hedderley, D.I. and Morgenstern, M.P. (2012) Fundamental fracture properties associated with sensory hardness of brittle solid foods. *Journal of Texture Studies* **43**, 49–62.
- Konopacka, D. and Plochanski, W.J. (2004) Effect of storage conditions on the relationship between apple firmness and texture acceptability. *Postharvest Biology and Technology* **32**, 205–211.
- Le Moigne, M., Maury, C., Bertrand, D. and Jourjon, F. (2008) Sensory and instrumental characterisation of Cabernet Franc grapes according to ripening stages and growing location. *Food Quality and Preference* **19**, 220–231.
- Olarte Mantilla, S.M., Collins, C., Iland, P.G., Johnson, T.E. and Bastian, S.E.P. (2012) Review: Berry Sensory Assessment: concepts and practices for assessing winegrapes' sensory attributes. *Australian Journal of Grape and Wine Research* **18**, 245–255.
- Olarte Mantilla, S.M., Collins, C., Iland, P.G., Kidman, C.M., Jordans, C. and Bastian, S.E.P. (2013) Comparison of sensory attributes of fresh and frozen wine grape berries using Berry Sensory Assessment. *Australian Journal of Grape and Wine Research* **19**, 349–357.
- Organisation Internationale de la Vigne et du Vin (2008a) Resolution VITI 1/2008. OIV standard on minimum maturity requirements for table grapes (Organisation Internationale de la Vigne et du Vin: Paris, France).
- Organisation Internationale de la Vigne et du Vin (2008b) Recueil international des méthodes d'analyse des vins et des moûts (Organisation Internationale de la Vigne et du Vin: Paris, France).
- Organisation Internationale de la Vigne et du Vin (2009) OIV descriptor list for grape varieties and *Vitis* species, 2nd edn (Organisation Internationale de la Vigne et du Vin: Paris, France).
- Péneau, S., Hoehn, E., Roth, H.-R., Escher, F. and Nuessli, J. (2006) Importance and consumer perception of freshness of apples. *Food Quality and Preference* **17**, 9–19.
- Río Segade, S., Giacosa, S., Gerbi, V. and Rolle, L. (2011a) Berry skin thickness as main texture parameter to predict anthocyanin extractability in winegrapes. *LWT – Food Science and Technology* **44**, 392–398.
- Río Segade, S., Orriols, I., Giacosa, S. and Rolle, L. (2011b) Instrumental texture analysis parameters as winegrapes varietal markers and ripeness predictors. *International Journal of Food Properties* **14**, 1318–1329.
- Río Segade, S., Giacosa, S., de Palma, L., Novello, V., Torchio, F., Gerbi, V. and Rolle, L. (2013a) Effect of the cluster heterogeneity on mechanical properties, chromatic indices and chemical composition of Italia table grape berries (*Vitis vinifera* L.) sorted by flotation. *International Journal of Food Science and Technology* **48**, 103–113.
- Río Segade, S., Giacosa, S., Torchio, F., de Palma, L., Novello, V., Gerbi, V. and Rolle, L. (2013b) Impact of different advanced ripening stages on berry texture properties of 'Red Globe' and 'Crimson Seedless' table grape cultivars (*Vitis vinifera* L. *Scientia Horticulturae* **160**, 313–319.
- Rolle, L., Giacosa, S., Gerbi, V. and Novello, V. (2011a) Comparative study of texture properties, color characteristics, and chemical composition of ten white table-grape varieties. *American Journal of Enology and Viticulture* **62**, 49–56.
- Rolle, L., Río Segade, S., Torchio, F., Giacosa, S., Cagnasso, E., Marengo, F. and Gerbi, V. (2011b) Influence of grape density and harvest date on changes in phenolic composition, phenol extractability indices, and instrumental texture properties during ripening. *Journal of Agricultural and Food Chemistry* **59**, 8796–8805.
- Rolle, L., Siret, R., Río Segade, S., Maury, C., Gerbi, V. and Jourjon, F. (2012) Instrumental texture analysis parameters as markers of table-grape and winegrape quality: a review. *American Journal of Enology and Viticulture* **63**, 11–28.
- Rolle, L., Giacosa, S., Gerbi, V., Bertolino, M. and Novello, V. (2013) Varietal comparison of the chemical, physical, and mechanical properties of five colored table grapes. *International Journal of Food Properties* **16**, 598–612.
- Saeleaw, M. and Schleining, G. (2011) A review: crispness in dry foods and quality measurements based on acoustic-mechanical destructive techniques. *Journal of Food Engineering* **105**, 387–399.
- Saklar, S., Urgan, S. and Katnas, S. (1999) Instrumental crispness and crunchiness of roasted hazelnuts and correlations with sensory assessment. *Journal of Food Science* **64**, 1015–1019.
- Salvador, A., Varela, P., Sanz, T. and Fiszman, S.M. (2009) Understanding potato chips crispy texture by simultaneous fracture and acoustic measurements, and sensory analysis. *LWT – Food Science and Technology* **42**, 763–767.
- Sato, A. and Yamada, M. (2003) Berry texture of table, wine, and dual-purpose grape cultivars quantified. *Hortscience: A Publication of the American Society for Horticultural Science* **38**, 578–581.
- Sato, A., Yamane, H., Hirakawa, N., Otobe, K. and Yamada, M. (1997) Varietal differences in the texture of grape berries measured by penetration tests. *Vitis* **36**, 7–10.
- Sato, A., Yamada, M., Iwanami, H. and Hirakawa, N. (2000) Optimal spatial and temporal measurement repetition for reducing environmental variation of berry traits in grape breeding. *Scientia Horticulturae* **85**, 75–83.
- Sato, A., Yamada, M., Iwanami, H. and Mitani, N. (2004) Quantitative and instrumental measurements of grape flesh texture as affected by gibberellic acid application. *Journal of the Japanese Society for Horticultural Science* **73**, 7–11.
- Sato, A., Yamada, M. and Iwanami, H. (2006) Estimation of the proportion of offspring having genetically crispy flesh in grape breeding. *Journal of the American Society for Horticultural Science* **131**, 46–52.
- Taniwaki, M., Hanada, T., Tohro, M. and Sakurai, N. (2009) Non-destructive determination of the optimum eating ripeness of pears and their texture measurements using acoustical vibration techniques. *Postharvest Biology and Technology* **51**, 305–310.
- Torchio, F., Giacosa, S., Río Segade, S., Mattivi, F., Gerbi, V. and Rolle, L. (2012) Optimization of a method based on the simultaneous measurement of acoustic and mechanical properties of winegrape seeds for the determination of the ripening stage. *Journal of Agricultural and Food Chemistry* **60**, 9006–9016.
- Varela, P., Chen, J., Fiszman, S. and Povey, M.J.W. (2006) Crispness assessment of roasted almonds by an integrated approach to texture description: texture, acoustics, sensory and structure. *Journal of Chemometrics* **20**, 311–320.
- Varela, P., Salvador, A. and Fiszman, S. (2009) On the assessment of fracture in brittle foods II. Biting or chewing? *Food Research International* **42**, 1468–1474.
- Vargas, A., Pérez, J., Zoffoli, J.P. and Pérez, A. (2001) Comparación de variables de textura en la medición de firmeza de bayas de uva Thompson seedless. *Ciencia e Investigación Agraria* **28**, 37–42.
- Zdunek, A., Cybulska, J., Konopacka, D. and Rutkowski, K. (2010a) New contact acoustic emission detector for texture evaluation of apples. *Journal of Food Engineering* **99**, 83–91.
- Zdunek, A., Konopacka, D. and Jesionkowska, K. (2010b) Crispness and crunchiness judgment of apples based on contact acoustic emission. *Journal of Texture Studies* **41**, 75–91.
- Zdunek, A., Cybulska, J., Konopacka, D. and Rutkowski, K. (2011) Evaluation of apple texture with contact acoustic emission detector: a study on performance of calibration models. *Journal of Food Engineering* **106**, 80–87.

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### Supporting information

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**Table S1.** Significant Pearson's correlation coefficients between instrumental texture attributes and berry size for seven table grape cultivars.