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VARIETAL COMPARISON OF THE CHEMICAL, PHYSICAL AND MECHANICAL PROPERTIES OF FIVE COLORED TABLE GRAPES

L. Rolle[1*], S. Giacosa[1], V. Gerbi[1], M. Bertolino[1], V. Novello[2]

[1] Dipartimento di Valorizzazione e Protezione delle Risorse Agroforestali, Settore di Tecnologie Alimentari, Università degli Studi di Torino, Via Leonardo da Vinci 44, 10095 Grugliasco, Torino, Italy

[2] Dipartimento di Colture Arboree, Università degli Studi di Torino, Via Leonardo da Vinci 44, 10095 Grugliasco, Torino, Italy

*Corresponding author [email: luca.rolle@unito.it; tel: +39 011 6708558; fax: +39 011 6708549]

ABSTRACT

The visual attributes of table grapes, their chemical constituents and mechanical properties are involved in consumer acceptability because they are correlated to sensory perception. Usually, instrumental measurements are preferred to the sensory evaluations because they reduce variations in subjective judgments and can be carried out more easily. In this work chemical-physical attributes and texture properties of five black table grapes (Alphonse Lavallée, Black magic, Cardinal, Perlon, Regina nera) were studied in order to identify significant varietal differences. Spectrophotometric and HPLC methods and Texture Analysis test were used to evaluate color index, sugars and acid composition, phenolic characteristics and mechanical properties of the skin and the pulp of berries. Many differences were found among varieties in technological maturity indexes, hydroxycinnamic acid, anthocyanin content and profile and relative CIE L*, a*, b* parameters, but the more relevant differences were found in mechanical properties. Principal Component Analysis showed that the TPA parameters (hardness, cohesiveness, gumminess, resilience) and berry skin characteristics (break skin energy, skin modulus of elasticy) were the best indices able to fulfill the aim of this work. Almost all the parameters showed differences among cultivars, confirming their importance in the characterization of the variety as well as in the assessment of potential consumer acceptability. In particular, the cultivars demonstrated different reactions to the compression test; thus, the texture analysis parameters can be appropriate to explain varietal differences and to allow their differentiation.

Keywords: Table grapes, Texture Analysis, Texture Profile Analysis, skin hardness, color index, anthocyanins.

INTRODUCTION

The grapevine, exploited for the production of wine, table grapes and raisins, is one of the most widely grown fruit trees in the world. About 25-30 % of the total grapes harvested are table grapes for fresh consumption; moreover, in recent years, an increase in the production of table grapes for fresh consumption has been observed.[1] Consumer acceptability of table grapes, as that of all fruits in general, is dependent on numerous attributes. In fact, both visual characteristics and chemical-physical properties are involved in the sensory and quality evaluation of table grapes. Moreover, nutritive and functional properties are becoming more and more important in determining consumer choice, even if the classical parameters such as soluble solids concentration (SSC), acid contents, SSC/acid ratio and skin color are still the main quality parameters in table grapes.[2-8] In particular for colored grapes, skin color is a quality factor of fundamental importance, since sight is the first of the senses to be used, and visual appreciation is decisive in the choice.[9] The total content of anthocyanins and the proportions between them, dependent mainly on the cultivar,[10] determine the final coloration of the grape skin.[11-13]

For fresh consumption, mechanical properties are among the most important factors determining the eating quality of table grapes. Sensory attributes such as skin friability, skin thickness and flesh firmness have been proposed to characterize commercial table grape cultivars.[2,14] Many of these sensory descriptors can be evaluated by instrumental measurements, and in many instances high correlations with the mechanical parameters determined by texture analysis were observed.[15,16] These instrumental measurements are often preferred to sensory evaluations because they reduce variations in subjective judgments and can be more easily used to collate data from different sources.

For table grapes, particular attention has been focused on the study of the mechanical properties of the pulp. In fact, crispness is the most desirable texture for table-use, and cultivars with a crisp flesh texture are important genetic materials for table-grape breeding.[17,18] The Texture Profile Analysis (TPA) test has been recently proposed to define the pulp texture characteristics.[19] Nevertheless, scientific contributions about physical-mechanical parameters of the berry skins of colored table grapes and of whole berries are scarce in the literature. Furthermore, only few reports are available on varietal differences of the mechanical properties of grape texture. The aim of this study is therefore to gain further insight into these aspects, as well as to investigate color characteristics and berry chemical composition in order to compare the characteristics of five colored table grape varieties grown in Italy.

MATERIALS AND METHODS

Grapes samples

Grape samples of five black table grape cultivars (*Vitis vinifera L.*) were collected at harvest from the experimental-collection vineyard, located at 300 m a.s.l. in Alessandria province (Piedmont, Italy). The study was carried out in 2009 on the following varieties: Alphonse Lavallée, Black magic, Cardinal, Perlon and Regina nera. Vines are planted 1.2 x 1.8 m apart, grafted onto the 196-17 C rootstock VSP trained and cane pruned. The vineyard is 10 years old. Technological parameters of ripeness were monitored at a regular interval of 5 days in the period August-September, the grapes of each variety were collected when three consecutive samplings (10 days) showed no increase of sugar content.[20] At their respective ripening time, each grape sample consisted of 30 bunches picked randomly from ten different vines. After transfer to the laboratory, a set of 600 berries per cultivar was randomly sampled. The measurements for the appraisal of grape mechanical properties were made on sub-samples of 30 berries for each texture test, taken from the 600 berry samples. Other sub-samples of 30 berries for each of the varieties were used for color determination. Thirty berries, three replicates of ten berries, were taken for organic acid and phenolic composition analysis. The must of the remaining berries were used for total soluble solids contents, pH and titratable acidity determinations. All the analysis and texture tests were performed on the same day as the berries were picked in order to avoid alterations.

Chemical analysis

Technological parameters of ripeness - Total soluble solids concentration (°Brix, as SSC) was measured using an Atago 0-32 °Brix temperature compensating refractometer (Atago Co., Tokyo, Japan), pH was determined by potentiometry using a Crison electrode (Carpi, Italy) and titratable acidity (g L^{-1} tartaric acid, as TA) was estimated using standard EEC methods.[21] The contents of citric, tartaric and malic acid (g kg^{-1} pulp) were analyzed using an HPLC system (P100-AS3000, Thermo Electron Corporation, Waltham, MA, USA) equipped with a Spectra Focus Diode Array Detector UV3000 set to 210 nm. The analyses were performed isocratically at 0.8 mL min^{-1} flow and 65°C column temperature, with a 300 × 7.8 mm i.d. Aminex HPX-87H cation exchange column and a Cation H^+ Microguard cartridge (Bio-Rad Laboratories, Hercules, CA, USA), using 0.0013 mol L^{-1} H_2SO_4 as mobile phase.[22] Data treatment was carried out using the ChromQuest™ chromatography data system (ThermoQuest, Inc, San Jose, CA, USA).

Phenol extraction and analysis - The berry skins, removed manually from the pulp and dried with absorbent paper, were quickly immersed in 25 mL of hydro-alcoholic buffer at pH 3.2, containing 2 g L^{-1} of $Na_2S_2O_5$ and 12 % of ethanol. The pulps were collected in a beaker containing 50 mg of $Na_2S_2O_5$. Skins and pulps were then separately homogenized with an Ultraturrax T25 (IKA Labortechnik, Staufen, Germany) and centrifuged for 5 min at 3000 × g at 20 °C. The supernatant was then used for analysis. Spectrophotometric methods were used to evaluate the total anthocyanin (mg malvidin-3-glucoside chloride kg^{-1} grape, as TAI) the total polyphenols (mg(+)-catechin kg^{-1} grape, as TP) in berry skin and pulp, and total hydroxycinnamic acids (mg caffeic acid kg^{-1} grape, as HCA) in the pulp.[23-26] The relative standard deviations (RSD) based on repeated analysis (n=20) of the same sample were 1.14, 1.58 and 1.82 % for TAI, TP and HCA, respectively.[25] The analysis of individual anthocyanins was performed using the same HPLC described above with the Spectra Focus Diode Array Detector operating at 520 nm, and after application of the berry skins extract to a SEP-PAK C18 cartridge (Waters Corporation, Milford, MA, USA) and elution with methanol. A LiChroCART column (25 cm x 0.4 cm i. d.) packed with LiChrosphere 100 RP-18 5-µm particles from Merck (Darmstadt, Germany) was used. The following solvents were used: solvent A = 10 % v/v formic acid in water; solvent B = 10 % v/v formic acid with 50 % v/v methyl alcohol in water. The solvent flow rate was 1 mL min^{-1} and the column temperature was 20 °C. The injection volume was 20 µL. The solvent gradient used was previously reported in the literature.[13,23,24] The identification of the free forms of anthocyanins in berry skin extracts was performed by comparison with external standards. The acylated forms of anthocyanins were identified by matching DAD spectrum and retention time of each chromatographic peak, and by comparing these with available data in the literature.[26,27] Individual anthocyanins were expressed in percentages.

Reagent and standards - Solvents of HPLC-gradient grade and all other chemicals of analytical-reagent grade were purchased from Sigma (Milan, Italy). The solutions were prepared in deionized water produced by a Purelab Classic system (Elga Labwater, Marlow, United Kingdom). Anthocyanin standards (Delphinidin-3-*O*-glucoside chloride, Malvidin-3-*O*-glucoside chloride, Peonidin-3-*O*-glucoside chloride, Cyanidin-3-*O*-glucoside chloride, Petunidin chloride) and phenol standards (Caffeic acid, (+)-Catechin) were supplied by Extrasynthèse (Genay, France). All the standards were stored at -20 °C away from light before use.

Physical and mechanical analysis

Color measurement and indexes - Before the color analysis, the bloom was removed from the grape skins by paper tissue. Three measurements were made around the equatorial belt of each berry. The color values, L*, a*, b*, C (chroma value) and H (hue angle) were determined[28] by a reflectance spectrophotometer Minolta CR-410 Chroma Meter (Minolta Corp., Osaka, Japan). Standard illuminant D_{65} was used as reference. Two indexes for each variety were calculated: CIRG = (180-H) / (L*+C), proposed as colorimetric index for the table grapes**,** and CIRG2 = (180-H) / (L*x C),[29] where H was calculated considering the hue values included between 360° and 270° as negative (e.g. 346° was taken as -14°).[30]

Mechanical properties of berry skin - For all texture analysis tests, the measurements were performed using an Universal Testing Machine TAxT2i Texture Analyzer (Stable Micro System, Godalming, Surrey**,** UK) equipped with a HDP/90 platform and a 5 kg load cell. All the acquisitions were carried out at 400 Hz using the Texture Expert Exceed software version 2.54 working in the MS Windows environment. Skin hardness was evaluated by puncture testing using a SMS P/2 needle probe and a speed test of 1 mm s^{-1}. The berries were punctured in the lateral face and three parameters were measured: berry skin break force (N, as F_{sk}), berry skin break energy (mJ, as W_{sk}) and Young's modulus of elasticity of the skin (N/mm, as E_{sk}).[31,32] Skin thickness (μm, as Sp_{sk}) was calculated as the distance between the point corresponding to the probe contact with the berry skin (trigger) and the platform base during a compression test.[32]

Mechanical properties of whole berry - Mechanical properties of whole berry were evaluated by Texture Profile Analysis test (TPA).[19,32,33] Each whole berry was compressed by an SMS P/35 flat probe under a deformation of the berry of 25 % with a waiting time between the two bites of two seconds using 1 mm s^{-1} as speed test.[32,33] From the force-time (deformation) curves (Figure 1), the typical TPA texture parameters were calculated by the software: hardness (N, as P_1), cohesiveness (adimensional, as $(A_2+A_{2W})/(A_1+A_{1W})$), gumminess (N, as hardness* cohesiveness), springiness (mm, as d_2), chewiness (mJ, as gumminess*springiness) and resilience (adimensional, as (A_{1w}/A_1)).[32,33] The time scale on the x-axis can be converted into deformation knowing the test speed.

Statistical analysis

Analysis of variance was applied to all the variables studied. The mean values obtained in the different categories were compared by one-way ANOVA and significant differences among means at $p < 0.01$ were determined by Tukey's test. Principal component analysis (PCA) was also performed. Both ANOVA and PCA were carried out using the statistical software SAS (SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

In order to minimize the influence of growing location on the measured parameters, in this comparative study we used only table grapes which were grown in the same vineyard. In fact, it is well known that many of the chemical, physical and mechanical properties studied are strongly influenced by environmental conditions.[15,25,34] Moreover, in order to not induce modifications of the chemical-physical fruit characteristics, plant growth, regulators were not used, although they are utilized as a common practice in table grape production.[6]

The organoleptic quality of the table grape greatly depends on the content and composition of sugars and organic acids in berries. Among the five varieties, the soluble solids concentrations ranged from 13.8 for Perlon to 22.4 for Regina nera, while the titratable acidity ranged from 5.0 g L^{-1} for Black magic to 10.4 g L^{-1} for Regina nera. (Table 1). Perlon grapes, although the low sugar accumulation may be assumed to have reached a satisfying ripening level on the basis of the SSC/TA ratio which was 20.2. In fact, according to the OIV resolution VITI 1/2008, the black table grapes are considered ripe with SSC ≥ 16 °Brix; when SSC is < 16 °Brix and > 12.5 °Brix, table grapes are considered ripe if the ratio between SSC (expressed as g L^{-1}) and TA (expressed as g L^{-1} tartaric acid) is higher than 20. In this comparative study, SSC/TA ranged between 14.7 in

Alphonse Lavallèe (with16.0 °Brix) and 25.0 in Black magic (with 14.2 °Brix), thus all the cultivars reached a good ripening level. Jayasena and Cameron[4] demonstrated that the acidity has a negative correlation with the degree of consumer satisfaction and that the SSC/TA ratio is the better predictor of the sensory attributes sweetness, sourness and flavor as compared with °Brix or acidity alone. In any case, although SSC, TA and sugar-acid balance in the table grape are important quality criteria of consumer acceptance, it is not possible to define a universally valid table grape quality standard because the consumer behavior is very different from country to country.[3] In this study, citric acid concentration showed little differences among varieties. Only Alphonse Lavallée (0.21 g kg^{-1} pulp) had a statistically higher value. Malic acid ranged from 0.99 to 3.21 g kg^{-1} pulp in the Black magic and Alphonse Lavallée, respectively. A very low variability was found in the tartaric acid values which ranged between 1.40 g kg^{-1} pulp for the Perlon to 1.73 g kg^{-1} pulp for the Cardinal grapes.

The phenolic composition of berry skin and flesh **is** reported in Table 2. Many differences were found among the varieties. In berry skin, TP ranged from 650 to 1685 mg (+)-catechin kg^{-1} of grape for Cardinal and Regina nera, respectively. Alphonse Lavallée was characterized by the highest content of anthocyanin (493 mg malvidin-3-glucoside chloride kg^{-1} berries) while Cardinal cultivar showed the lowest one (116 mg malvidin-3-glucoside chloride kg^{-1} berries). This range of anthocyanin content is in accordance with literature data;[35] only Alphonse Lavallée showed **a** lower TAI with respect to other studies, that, on the other hand, reported values very different between them.[11,36] It is interesting to note that, although the skin of the colored grapes contains anthocyanins, the total polyphenols are not always higher than those of white table grapes. In fact, some white table grape cultivars such as Pizzutello bianco and Sultanina, analyzed with the same analytical method, showed a TP content higher than 1180 mg (+)-catechin kg^{-1} of grape, and the skin of Pansè precoce reached a TP content of 2052 mg (+)-catechin kg^{-1} of grape.[20] The same behavior has been observed in wine grapes.[37] Differences in TP contents of pulp were noticed among the cultivars. Alphonse Lavallée was the variety characterized by the highest TP in flesh (404 mg (+)-catechin kg^{-1} of grape). The pulp of this variety also contained the highest content of HCA: 79 mg caffeic acid kg^{-1} berries. All the other varieties showed HCA values close to 60, while Black magic had a statistically lower content (29 mg caffeic acid kg^{-1} berries). The HCA data are in agreement with those reported in the literature.[38]

Results detailing the variation of anthocyanin patterns are reported in Table 3. The composition of anthocyanins is primarily decided by genetic factors, and the relative content of any one anthocyanin is stable in grape skin for a given cultivar.[27] Therefore, as a consequence, the ratio among anthocyanins can be used for chemotaxonomical classifications of colored grapes cultivars.[11] In this study, many differences were found among the varieties. The monoglucoside group made up the highest proportion of the anthocyanin form: the values ranged between 65.03 % for Black magic to 92.36 % for Perlon grapes. Moreover, Perlon was characterized by the smallest proportions of acetyl derivatives (0.85 %) and cinnamoyl derivatives (6.36 %). In contrast, the highest proportions of acetyl derivatives (8.68 %) and cinnamoyl derivatives (31.17 %) were found in Regina nera and Black magic, respectively. In general, the most abundant anthocyanin compounds in grape skin were malvidin monoglucoside derivative forms (from 50.99 to 82.14 %), except for Cardinal where peonidin monoglucoside derivative forms were predominant (69.06 %), as already reported in the literature.[11,39]

Grape CIELAB parameters and the calculated colorimetric indexes highlight**ed** moderate differences among the cultivars (Table 4). Nevertheless, the CIRG2 index showed the best potential for evaluating the berry skin color of the five varieties, allowing to distinguish grapes that, based on the color O.I.V code 225[40], would be classified in the same group (5, dark red violet). The values of CIRG2 ranged between 1.37 in cv Cardinal to 5.93 in cv Alphonse Lavallée. L*, a*, b*, hue angle (H) and chroma (C) values were in agreement with data reported in the literature for grapes showing O.I.V. codes 4 and 5.[11,29]

Skin mechanical properties of the five colored table grapes are reported in Table 5. Many differences were found. The highest berry skin break force was associated with Alphonse Lavallée with an average value of F_{sk} of 0.585 N. Instead, the lowe**st** values of hardness parameters were found in Black magic grapes skin: 0.329N for F_{sk} and 0.068 mJ for W_{sk}. Under the same postharvest storage conditions, the dehydration kinetics of grapes is influenced by the cultivar.[41] In fact, varieties characterized by lower skin hardness show a quicker weight loss, [41] decreasing therefore their shelf life.

Because of the high variability of the Sp_{sk} data, few differences were found within the table grape varieties with respect to skin thickness. This characteristic may influence the texture desirability of grapes, and, in those varieties with thick skins, if not associated with a high skin friability, **it** would limit their commercial acceptance.[2] On the other hand, the thickness and toughness of the skin are factors which contribute to the resistance of the grape against fungal pathogens and handling injury during harvest, packing, transport and storage.[42] Perlon (305 μm) and Alphonse Lavallée (269 μm) showed higher Sp_{sk} values. No correlations were found between F_{sk} and Sp_{sk} parameters, in accordance with data already reported in a previous study.[20] On the basis of these results, the skin mechanical properties of table grapes, and in particular F_{sk}, can be considered as good parameters for differentiating several varieties and could be suggested as varietal markers, since these parameters are also little influenced by the ripening stage of the grape, as was also demonstrated for wine-grapes.[25,32]

Texture characteristics determined with the TPA test allow the different cultivars to be discriminated. In fact, significant varietal differences were found (Table 6). Based on each berry texture propert**y**, except for gumminess, the varieties can be classified into several groups. In this double compression test, the influence of the pulp and skin properties on berries mechanical characteristics is aggregated.[43] Black magic (16.718 N) had the hardest berries while Regina nera (5.237 N) had the softest. Moreover, Regina nera was characterized by berries with low gumminess (3.419 N) and Perlon by lowest springiness values (2.766 mm). Higher values of chewiness were found in berries of the Cardinal variety (23.789 mJ). Black magic berries were instead identified by the lowest cohesiveness value (0.359). However, the resilience, a dimensionless parameter which represents how well a berry "fights to regain its original shape" after the first compression, can be considered the best texture parameter to characterize the black table grape varieties, also because this variable is independent of the fruit’s size. Resilience was the highest in Alphonse Lavallée (0.475) while Black magic and Cardinal showed the two lowest values, 0.193 and 0.244 respectively.

In general, with respect to skin texture parameters, the instrumental TPA parameters of the whole berry evolve throughout ripening[14] and the change continues more or less intensely during post-harvest in relation to the various techniques of preservation and packaging.[44] The cohesiveness value increases during grape ripeness[15] and decreases in the post-harvest period.[19] Therefore, this parameter can be also used as **a** grape ripeness predictor.[32] Although some mechanical properties between table and wine grape showed similar values and behaviors during ripening, analysis by the texture profile parameters hardness, cohesiveness, gumminess and chewiness enables discrimination of the two types of grapes.[33] In fact, the flesh texture of table grapes, measured instrumentally, is harder than that of wine grapes.[18]

In the present study, Principal Components Analysis (PCA) was performed for a better understanding of the differences found among grapes according to the variety and the chemical, physical and mechanical parameters (Figure 2). From the loadings of selected variables (Table 7), PC1 (71.18 % total variance) was most highly correlated with the skin properties E_{sk} and W_{sk} as well as with TPA parameters of whole berry hardness, resilience, cohesiveness and gumminess. CIRG and, partially, flesh total phenols dominated in PC2 (14.73 % total variance), while gumminess and resilience were correlated with PC3 (11.81 % total variance). PC1 separated clearly the 5 cultivars, while PC2 separated only Cardinal from Black magic, since the other 3 cultivars were almost lineated. By overlapping the variable chart and the variety chart, it was evident that Regina nera was characterized mostly by the resilience and Black magic by hardness.

CONCLUSION

The main aim of this comparative study was to investigate chemical composition, physical and mechanical attributes in order to compare the characteristics of five colored table grape varieties grown in Italy. The results acquired showed many differences among the studied varieties in each of the considered parameters, confirming their importance in characterization of the variety as well as in the assessment of potential consumer acceptability. In particular, the cultivars demonstrated notable diversity in the technological parameters of ripeness as revealed by the SSC/TA ratio range. Minor importance in the varietal differentiation was seen in the organic acid composition. On the contrary, the total content of anthocyanin and of hydroxycinnamic acids were successful varietal markers. However, among the phenolic compounds, the anthocyanin profile confirmed the best potential in the grape chemotaxonomic classification; moreover, it is strongly associated with the genetic inheritance of grape cultivars and is independent of the seasonal conditions or production area, as previously reported in the scientific literature. Instead, although linked with anthocyanin content and profile, both the CIELab parameters and relative calculated indexes (CIRG and CIRG2) highlighted moderate differences among the cultivars.

Relevant differences were found in mechanical properties. In fact, the cultivars demonstrated different behaviors to the applied mechanical stress; thus, together, berry skin and pulp mechanical properties can be appropriate to explain varietal differences and to allow their differentiation. In accordance with the Principal Component Analysis results, the TPA parameters (hardness, cohesiveness, gumminess, resilience) and berry skin characteristics (break skin energy, skin modulus of elasticy) were the best indices able to fulfill this aim.

This newly acquired knowledge should be of interest to operators in the viticulture and postharvest sectors, including breeders, helping them to recognize the behavior of each variety and to better satisfy the requirements of the market.

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Table 1 - Solid soluble concentration (SSC), titratable acidity (TA), SSC/TA ratio, pH and acid composition of colored table grapes.

	SSC (°Brix; g L^{-1})	TA (g L^{-1} tartaric acid)	SSC (g L^{-1})/TA	pH	Tartaric acid (g kg^{-1} pulp)	Malic acid (g kg^{-1} pulp)	Citric acid (g kg^{-1} pulp)
Alphonse Lavallée	16.0; 146	9.9	14.7	3.09	1.69±0.05 A	3.21±0.99 A	0.21±0.03 A
Black magic	14.2; 125	5.0	25.0	3.44	1.51±0.05 A	0.99±0.28 B	0.04±0.01 B
Cardinal	17.3; 159	9.5	16.7	3.42	1.73±0.13 A	1.56±0.35 AB	0.06±0.01 B
Perlon	13.8; 121	6.0	20.2	3.10	1.40±0.24 A	1.17±0.21 B	0.05±0.01 B
Regina nera	22.4; 218	10.4	21.0	3.05	1.71±0.06 A	1.61±0.26 AB	0.04±0.01 B
Significance	-	-	-	-	*	**	***

Average value ± standard deviation (*n*=3). Different letters within the same column mean significant differences according to a Tukey test ($p<0.01$).

Statistical significance:***=$P<0.001$; **=$P<0.01$; *=$P<0.05$; ns= not significance.

Table 2 - Total polyphenols (TP), total anthocyanins (TAI) and hydroxycinnamic acids (HCA) of colored table grapes.

	TP skin (mg (+)-catechin kg^{-1} berries)	TAI skin (mg malvidin-3-glucoside chloride kg^{-1} berries)	TP flesh (mg (+)-catechin kg^{-1} berries)	HCA flesh (mg caffeic acid kg^{-1} berries)
Alphonse Lavallée	1330±20 A	493±68 A	404±5 A	79±3 A
Black magic	1298±126 A	209±98 BC	101±17 B	29±2 C
Cardinal	650±50 B	116±15 C	150±17 B	57±2 B
Perlon	772±175 B	243±17 B	152±28 B	53±4 B
Regina nera	1685±111 A	260±32 B	317±56 A	59±5 B
Significance	***	***	***	***

Average value ± standard deviation (*n*=3). Different letters within the same column mean significant differences according to a Tukey test (p<0.01).

Statistical significance:***=P<0.001; **=P<0.01; *=P<0.05; ns= not significance.

Table 3 – Anthocyanin profile of colored table grapes.

	Simple Glucosides	Acetyl-glucosides	Cinnamoyl-glucosides*	∑ of delphinidin derivative forms	∑ of cyanidin derivative forms	∑ of petunidin derivative forms	∑ of peonidin derivative forms	∑ of malvidin derivative forms
Alphonse Lavallée	81.02±5.55 B	2.00±0.42 B	16.62±4.81 BC	13.57±2.57 A	3.65±1.34 A	12.89±1.65 A	18.90±1.06 C	50.99±5.97 B
Black magic	65.03±1.03 C	1.98±0.21 B	31.17±1.09 A	1.98±0.21 BC	0.59±0.14 B	4.67±0.20 BC	10.62±1.26 CD	82.14±1.21 A
Cardinal	87.51±0.81 AB	1.53±0.04 B	10.29±0.75 CD	0.68±0.13 C	3.28±0.36 A	2.07±0.21 C	69.06±4.29 A	24.91±4.11 C
Perlon	92.36±0.34 A	0.85±0.12 C	6.36±0.38 D	4.62±0.42 BC	3.17±0.12 A	6.35±0.45 B	31.68±3.49 B	54.18±3.38 B
Regina nera	66.43±0.87 C	8.68±0.34 A	23.02±0.49 B	5.14±0.14 B	2.28±0.21AB	6.55±0.05 B	8.60±1.11 D	77.43±1.51 A
Significance	***	***	***	***	**	***	***	***

* Cinnamoyl-glucosides included both p-coumaroyl and caffeoyl anthocyanin forms. Average value ± standard deviation (*n*=3). Different letters within the same column mean significant differences according to a Tukey test (p<0.01). Statistical significance:***=P<0.001; **=P<0.01; *=P<0.05; ns= not significance.

Table 4 - CIE L*, a*, b* parameters and calculated color indexes of colored berry skin of table grapes.

	O.I.V. color	L*	a*	b*	C (Chroma)	H (hue)	CIRG (180-h)/(L*+C)	CIRG2 (180-h)/(L*×C)
Alphonse Lavallée	5	26.64 ± 0.46 B	1.24 ± 0.35 B	-0.27 ± 0.41 B	1.32 ± 0.37 B	-14.42 ± 14.73 B	6.96 ± 0.61 A	5.93 ± 1.73 A
Black magic	5	26.13 ± 0.92 B	2.59 ± 0.86 B	-0.18 ± 0.31 B	2.62 ± 0.85 B	-4.87 ± 7.43 AB	6.45 ± 0.44 A	2.94 ± 0.87 BC
Cardinal	4	28.57 ± 1.53 A	5.61 ± 2.44 A	0.65 ± 0.77 A	5.68 ± 2.48 A	4.79 ± 8.23 A	5.18 ± 0.69 B	1.37 ± 0.79 C
Perlon	5	26.59 ± 0.80 B	2.41 ± 1.26 B	-0.22 ± 0.50 B	2.47 ± 1.24 B	-9.24 ± 12.85 AB	6.53 ± 0.56 A	3.37 ± 1.17 B
Regina nera	5	25.68 ± 0.87 B	1.95 ± 0.51 B	-0.44 ± 0.23 B	2.02 ± 0.51 B	-13.28 ± 6.58 B	6.99 ± 0.29 A	3.98 ± 1.13 B
Significance		***	***	***	***	**	***	***

Average value ± standard deviation (*n*=30). Different letters within the same column mean significant differences according to a Tukey test (p<0.01). Statistical significance:***=P<0.001; **=P<0.01; *=P<0.05; ns= not significance.

Table 5 - Mechanical properties of the berry skins of the colored table grapes: F_{sk} = Berry skin break force, W_{sk} = Berry skin break energy, E_{sk} = Young's modulus of Skin, Sp_{sk} = Berry skin thickness.

	F_{sk} (N)	W_{sk} (mJ)	E_{sk} (N/mm)	Sp_{sk} (µm)
Alphonse Lavallée	0.585 ± 0.136A	0.287 ± 0.104A	0.597 ± 0.135B	269 ± 72A
Black magic	0.329 ± 0.069D	0.068 ± 0.020C	0.782 ± 0.180A	166 ± 35B
Cardinal	0.519 ± 0.082AB	0.206 ± 0.109B	0.715 ± 0.214AB	181 ± 48B
Perlon	0.423 ± 0.084C	0.152 ± 0.084B	0.660 ± 0.219AB	305 ± 69A
Regina nera	0.504 ± 0.104BC	0.346 ± 0.118A	0.363 ± 0.081C	213 ± 41B
Significance	***	***	***	***

Average value ± standard deviation (n=30). Different letters within the same column mean significant differences according to a Tukey test ($p<0.01$). Statistical significance:***=$P<0.001$; **=$P<0.01$; *=$P<0.05$; ns= not significance.

Table 6 - Mechanical properties of whole berry of the colored table grapes: Texture Profile Analysis parameters.

	Hardness (N)	Cohesiveness (-)	Gumminess (N)	Springiness (mm)	Chewiness (mJ)	Resilience (-)
Alphonse Lavallée	9.084 ± 2.109C	0.616 ± 0.078A	5.602 ± 1.447A	3.644 ± 0.424B	20.807 ± 6.983A	0.475±0.054A
Black magic	16.718 ± 2.344A	0.359 ± 0.031C	6.616 ± 1.145A	3.167 ± 0.257C	19.223 ± 4.724AB	0.193±0.023E
Cardinal	11.294 ± 3.294B	0.507 ± 0.071B	5.657 ± 1.609A	4.147 ± 0.497A	23.789 ± 7.706A	0.244±0.040D
Perlon	11.012 ± 2.312BC	0.505 ± 0.048B	5.508 ± 1.070A	2.766 ± 0.214D	15.318 ± 3.629BC	0.289±0.032C
Regina nera	5.237 ± 1.185D	0.646 ± 0.090A	3.419 ± 0.984B	3.081 ± 0.477CD	10.654 ± 4.154C	0.332±0.051B
Significance	***	***	***	***	***	***

Average value ± standard deviation (*n*=30). Different letters within the same column mean significant differences according to a Tukey test (p<0.01). Statistical significance:***=P<0.001; **=P<0.01; *=P<0.05; ns= not significance.

Table 7 – Principal Component Analysis: loadings of selected parameters in the first three principal components.

	PC1	PC2	PC3
Hardness	-0.931	0.350	0.045
W_{sk}	0.919	-0.323	0.039
E_{sk}	-0.944	0.077	0.303
Resilience	0.894	-0.034	0.446
Cohesiveness	0.936	-0.304	0.168
Gumminess	-0.804	0.128	0.558
CIRG	0.659	0.732	0.063
SSC/TA	-0.797	-0.321	0.061
TP flesh	0.639	0.586	0.281
% of variance	71.18	14.73	11.81

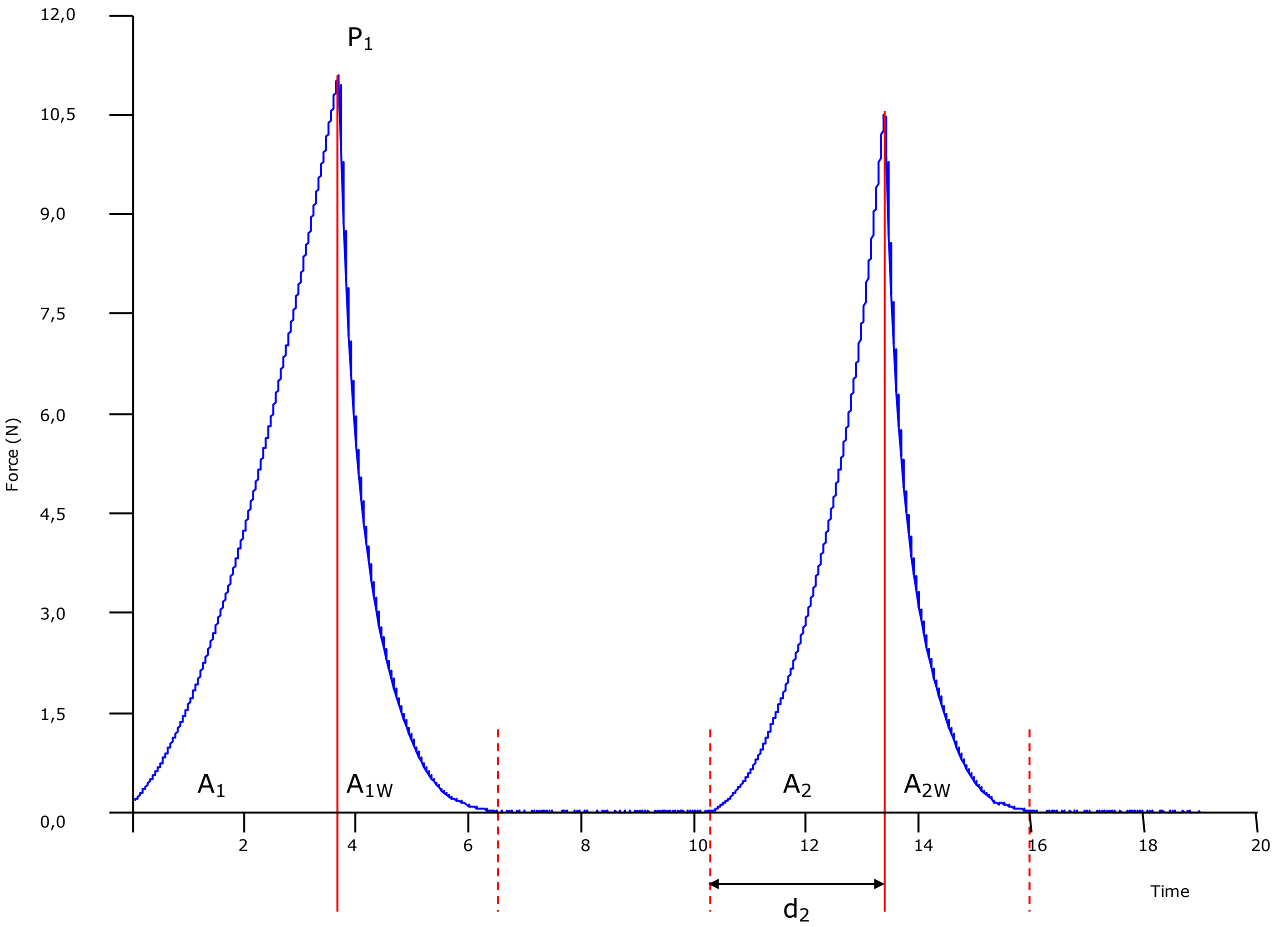

Figure 1 - Typical force-time (deformation) curves corresponding to Texture Profile Analysis (TPA). From this curve, six TPA texture parameters were calculated: hardness (N, as P_1), cohesiveness (adimensional, as $(A_2+A_{2W})/(A_1+A_{1W})$), gumminess (N, as hardness* cohesiveness), springiness (mm, as d_2), chewiness (mJ, as gumminess*springiness) and resilience (adimensional, as $(A_{1w/}A_1)$).

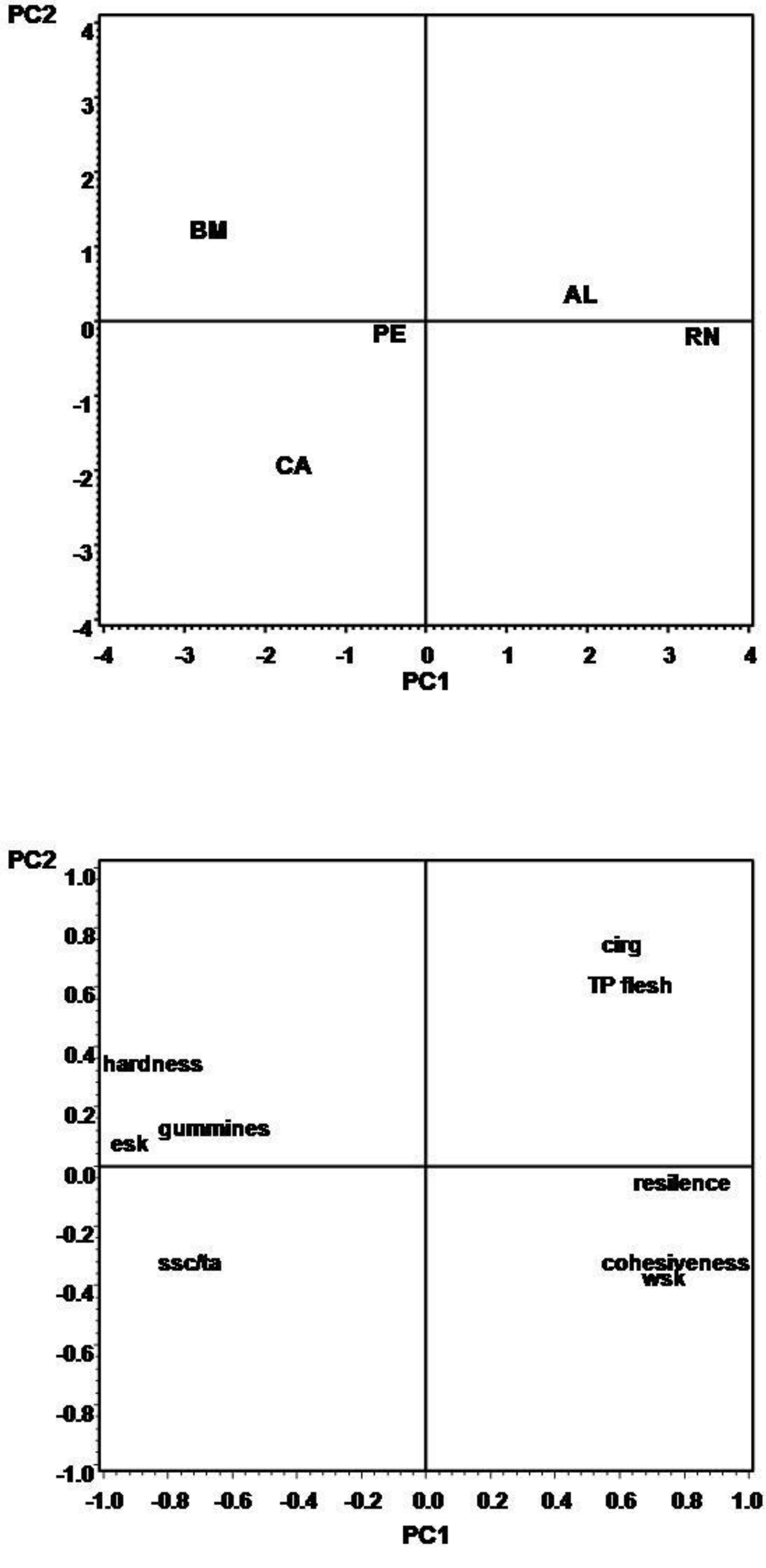

Figure 2 - Principal component analysis: scores of selected parameters of the colored table grapes. AL = Alphonse Lavallée, BM = Black magic, CA = Cardinal, PE = Perlon, RN = Regina nera.