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Evaluation of indexes for the quantitative and objective estimation of grapevine bunch compactness

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Summary

Bunch compactness is a key factor on the determination of grape quality. The use of qualitative visual systems for its determination is quite controversial, hindering some studies that require objective and quantitative measures of the trait. Here, eleven indexes published in literature and eight designed in this survey were tested with three different criteria to determine their usefulness for the estimation of bunch compactness. A sample of 110 grape bunches of different morphology, from 11 different varieties, were classified by a panel of 14 judges according to the visual OIV descriptor Nº 204. Besides, a number of measures were taken from the same bunches, which were used for the indexes' calculations. Several indexes designed here proved to be more suitable to obtain quantitative estimations for this trait in a genetically diverse set of varieties than the indexes previously published. Two of the selected indexes, CI-18 and CI-19, are based on the combination of six metrics from bunches (bunch weight, number of berries per bunch, number of seeds per berry, bunch length, first ramification length and either pedicel length or number of ramifications per bunch, respectively). These two indexes are more suitable for inter-varietal studies where obtaining quantitative data is critical. Other selected index (CI-12) is based on two easy-to-measure characteristics of the bunch (weight and length), and it is proposed as a fast estimator of bunch compactness for the viticulture sector.

K e y w o r d s : Bunch architecture, Bunch density, Bunch morphology, Compactness index, *Vitis vinifera*.

Introduction

Bunch compactness is a major factor affecting the quality of wine and table grapes. Compact bunches show favourable conditions for the development of different grape pests and diseases, such as the moth *Lobesia botrana* (Fermaud, 1998, Ioratti *et al.* 2011) or the rot fungi *Aspergillus* spp. (Leong *et al.* 2006, Hocking *et al.* 2007) and, especially, *Botrytis cinerea* (Ferreira *et al.* 1987, Vail *et al.* 1991, 1998, Gabler *et al.* 2003, Valdés-Gómez *et al.* 2008, Hed *et al.* 2009, Evers *et al.* 2010). The presence of these phytopathogens reduces crop yield and grape and wine quality, thus dropping economic profits (Moschos 2006, Ky *et al.* 2012). Among the reasons given to the major incidence of these organisms in compact bunches, some authors have pointed out the poor air circulation and sun exposure of the inner parts of the bunches (Vail *et al.* 1991, Molitor *et al.* 2011b), as well as different changes in the epicuticular wax layer development in the areas where berries are in contact (Marois *et al.* 1986, Gabler *et al.* 2003), and the formation of microcracks in the cuticle (Becker and Knoche, 2012). Moreover, berries may burst due to high pressure inside compact bunches (Molitor *et al.* 2011a), providing water and nutrients for the growth of these organisms. On the other hand, the number of interior berries increases with bunch compactness (Vail *et al.* 1991). These berries may not receive the sun irradiation needed to achieve an adequate phenolic maturity, leading to a heterogeneous ripeness of the bunch. Consequently, consumers, food industry and winemakers prefer grape bunches with certain values of compactness considered of higher quality (Nelson *et al.* 1970, Ikeda *et al.* 2004, Viana *et al.* 2011).

Although bunch compactness is a trait with a large agronomic and commercial relevance, little is known about its genetic basis. Some reasons might be its multifactorial nature and the difficulty to obtain objective and quantitative data for this trait, needed for an accurate phenotyping. Many studies (Intrieri *et al.* 2008, Tardáguila *et al.* 2008, Hed *et al.* 2009, Palliotti *et al.* 2011, Viana *et al.* 2011, Gatti *et al.* 2012) estimate it according to the visual descriptor proposed by the International Organization of Vine and Wine (O.I.V. 2007), while other authors have developed specific visual rating systems for its evaluation (Miele *et al.* 1978, Firoozabady *et al.* 1987, Gabler *et al.* 2003, Zabadal *et al.* 2006, Evers *et al.* 2010). Thus, the lack of a globally accepted criterion and the subjectivity linked to a visual system makes it difficult to compare results between different studies. Trying to solve it, and looking for a quantitative evaluation of bunch compactness, some authors have indirectly evaluated this trait through the determination of other characteristics of the grape bunch that vary with compactness. For instance, studying the degree of compression between the berries, measuring the force required to create a certain gap between two contiguous berries (Vail *et al.* 1991, 1998) or the suppleness of the bunches, determining the bending angle of the bunch (Evers *et al.* 2010, Schildberger *et al.* 2011, Molitor *et al.* 2011b).

On the other hand, several studies have proposed various relationships based on metrics of components of the grape bunch for the estimation of bunch compactness

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(Christodoulou *et al.* 1967, Sepahi 1980, Ferreira *et al.* 1987, Pommer *et al.* 1996, Fermaud, 1998, Shavrukov *et al.* 2004, Valdés-Gómez *et al.* 2008, Sternad-Lemut *et al.* 2010). Thus, this trait has been indirectly estimated (I) volumetrically, evaluating the empty spaces that appear in bunches as their compactness decreases (Sepahi 1980, Shavrukov *et al.* 2004); (II) by the number, weight or volume of the berries per centimetre of rachis (Sepahi 1980, Pommer *et al.* 1996, Fermaud 1998, Valdés-Gómez *et al.* 2008, Sternad-Lemut *et al.* 2010); and (III) by the relationship between the weight of the bunch and its morphological volume (Ferreira *et al.* 1987), ratio that can be considered as the average density of the bunch. These estimations have been published in literature in the form of indexes, and they seem to be the most interesting system for the indirect evaluation of bunch compactness, mainly because of their simplicity, their potential applicability to different grape varieties, and by not requiring complex measuring devices and large cost investments for its evaluation. The published indexes have been obtained from the evaluation of a reduced number of grape varieties, from the evaluation of compactness within clones of the same variety or from the study of plants of the same cultivar subjected to different agrochemical treatments. In some cases the use of such specific indexes may be convenient, and give place to more reliable results, but their use in intervarietal comparative studies (such as genetic association studies) is uncertain.

In this sense, the aim of this study was to evaluate the usefulness of several indexes, either previously published in literature or newly designed, for an objective and quantitative estimation of bunch compactness that was useful for intervarietal studies of this trait, knowing that compactness could be affected by different factors in different varieties.

Fig. 1: Grape bunches showing different grade of compactness according to the O.I.V. 204 descriptor (O.I.V. 2007). **1**: Very loose bunch ('Aramon'); **3**: Loose bunch ('Ruby Seedless'); **5**: Medium bunch ('Naparo'); **7**: Dense bunch ('Monastrell'); **9**: Very dense bunch ('Bobal'). Squares in the background have 1 cm^2.

Material and Methods

Plant Material: Eleven grapevine (*Vitis vinifera* L.) varieties previously identified by genetic analysis were selected for this study: 'Aramon', 'Bobal', 'Cabernet Franc', 'Cinsaut', 'Danugue', 'Derechero de Muniesa', 'Garnacha', 'Monastrell', 'Moravia Agria', 'Naparo' and 'Ruby Seedless'. They belong to the "Grapevine Germplasm Collection" of CIDA (Gobierno de La Rioja), located in Agoncillo. All varieties shared the same training system (double-T cane), row orientation (North/South) and cultural practices. All the plants, grafted onto 110 Richter rootstocks, were planted between 1982 and 1993 with a density of 4545 plants ha^{-1} (2.0 m x 1.1 m). The varieties were selected to represent different bunch compactness. They showed a high variability in those characteristics that may affect compactness, as shown in Fig. 1 and detailed in Tab. 1.

Characterization of grape bunches: A total of 110 bunches were included in this study, and eve-

Table 1

Average, minimum and maximum values for the grape bunch characteristics evaluated in this study. N: number of bunches; S.D.: standard deviation

	N	Average	S.D.	Min. value	Max. value
Compactness[a]	110	5.80	2.00	1.00	9.00
Actual bunch volume (mL)	108	228.67	115.15	60.00	570.00
Morphological bunch volume (mL)	110	425.59	210.84	150.00	1040.00
Conical bunch volume (mL)	110	581.87	338.23	132.06	1799.40
Bunch weight (g)	110	239.19	114.36	66.00	565.00
Bunch length (cm)	110	17.40	4.17	10.30	31.00
Bunch width (cm)	110	10.88	2.04	7.00	17.60
Berries per bunch	110	148.09	65.40	61.00	395.00
Berry length (mm)	110	13.64	2.36	8.66	19.37
Berry width (mm)	110	12.85	1.81	8.77	16.45
Seeds per berry	110	1.72	0.69	0.00	2.93
Rachis weight (g)	110	9.27	4.47	2.00	27.00
Ramifications per bunch	110	24.82	7.20	12.00	44.00
Peduncle length (mm)	110	41.95	14.43	15.60	77.23
First to seventh rachis node length (mm)	110	55.41	13.68	26.39	94.10
First ramification length (mm)	110	52.95	26.48	14.03	160.00
Second ramification length (mm)	110	49.95	29.01	7.23	154.07
Pedicel length (mm)	110	6.71	0.86	5.31	9.30

[a]: Evaluated according to the OIV descriptor Nº 204 by 14 trained judges.

ryone was treated and analysed independently. Ten grape bunches were sampled per variety at harvest time (modified E-L stage 38 (Coombe 1995)) from, at least, three different plants. Bunch wings (if clearly differentiated from adjacent bunch branches) were cut because of the different compactness they may show respecting to the main bunch, i.e. only primary bunches, according to OIV descriptor Nº 206 were considered (O.I.V. 2007).

Bunch compactness was rated according to OIV descriptor Nº 204 (O.I.V., 2007) by a panel formed by 14 experienced judges to minimize the problem linked to its subjectivity. This descriptor categorizes a bunch into one out of five categories, from 1 (very loose) to 9 (very dense), based on the amount of visible pedicels and the mobility of the berries. Independently, every bunch was morphologically described using quantitative and objective descriptors (Tab. 2). Briefly, the weight of each bunch was determined by means of a scale (Blauscal, AC-5000), and the actual and morphological volumes were determined by immersion in a bucket filled with water, measuring the volume of water displaced. For the determination of the morphological volume, bunches were wrapped with a self-adherent plastic film, modifying the procedure suggested by Ferreira *et al.* (1987). In this process, we tried to maintain the natural shape and morphology of bunches. The conical volume of the bunch was calculated using the standard formula $V_{cone} = (\pi r^2 l)/3$, where radius (r) was taken as equivalent to a half of the bunch width, and length (l), the length of the bunch. Then bunches were threshed by hand, separating the rachis and the berries, whose number was counted. Regarding the rachis, the length of the first and second branches, the length of the six first internodes and the length of the peduncle were determined using digital callipers (Mitutoyo, CD-15DCX). Fifteen pedicels per bunch were randomly chosen to determine their length with the same tool. Then, 15 berries per bunch were randomly chosen to measure their length and width as well as their number of seeds. For the latter four characteristics, the averages of the 15 measurements were used.

Evaluation of bunch compactness indexes: Eleven indexes published in literature and eight new indexes designed in this work were evaluated to determine their usefulness to measure bunch compactness in an objective way. These indexes, shown in Tab. 3, were calculated for our sample of 110 bunches. Because in our work the length of the rachis was not evaluated, in those indexes in which this variable appeared it was substituted by the length of the bunch. The criteria followed in this work to evaluate the usefulness of every index were as follows:

1. In first place, Kendall's *Tau-b* correlation coefficients were determined between the mode value given by the visual evaluation panel and the value given by any index calculated for the 110 bunches.
2. As stated by Sepahi (1980), the 110 bunches were sorted in increasing order for the compactness value, according to the average value given by the visual

Table 2

Descriptors used for the evaluation of bunch compactness and the 22 architectonical elements of the bunch evaluated in this work

Name	Description	Unit	Ref.
Compactness	Visual compactness of the bunch	-	OIV descriptor Nº204
Actual bunch volume	Actual volume of the bunch	mL	-
Morphological bunch volume	Apparent volume of the bunch	mL	Modified from Ferreira *et al.* (1987)
Conical bunch volume	$\frac{\pi \times (\text{Bunch width}/2)^2 \times \text{Bunch length}}{3}$	mL	-
Bunch weight	Weight of the bunch	g	-
Bunch length	Distance from the uppermost to the lowest berry of the bunch	cm	OIV descriptor Nº202
Bunch width	Maximum distance between the lateral berries of the bunch	cm	OIV descriptor Nº203
Berries per bunch	Total number of berries of the bunch	-	-
Berry length	Mean value of the length of 15 non deformed berries	mm	OIV descriptor Nº220
Berry width	Mean value of the width of 15 non deformed berries	mm	OIV descriptor Nº221
Seeds per berry	Mean value of the number of seeds of 15 berries	-	-
Rachis weight	Weight of the bunch rachis	g	-
Ramifications per bunch	Number of ramifications of the bunch	-	-
Peduncle length	Distance from insertion point on the shoot to the 1st ramification of the bunch	mm	OIV descriptor Nº206
First internode length	Distance from first to second nodes of the rachis	mm	-
Second internode length	Distance from second to third nodes of the rachis	mm	-
Third internode length	Distance from third to fourth nodes of the rachis	mm	-
Fourth internode length	Distance from fourth to fifth nodes of the rachis	mm	-
Fifth internode length	Distance from fifth to sixth nodes of the rachis	mm	-
Sixth internode length	Distance from sixth to seventh nodes of the rachis	mm	-
First ramification length	Length of the first ramification of the rachis	mm	-
Second ramification length	Length of the second ramification of the rachis	mm	-
Pedicel length	Mean value of 15 measurements: distance from insertion to ramification	mm	OIV descriptor Nº238

Table 3

Bunch compactness indexes (CI) evaluated in this work

Index	Equation[a]	Ref.
CI-1	BW (g)/[RL (cm) + 1RL (cm)]	FERMAUD (1998)
CI-2	BB/[RL (cm) + 1RL (cm)]	VALDÉS-GÓMEZ *et al.* (2008)
CI-3	BB/BL (cm)	POMMER *et al.* (1996)
CI-4	[ABV (mL)/MBV (mL)] × 100	SEPAHI (1980)
CI-5	$\frac{\text{ABV (mL)}}{\text{RL (cm) + 1RL (cm) + 2RL (cm)}}$	SEPAHI (1980)
CI-6	$\frac{\text{BW (g)}}{\text{RL (cm) + 1RL (cm) + 2RL (cm)}}$	SEPAHI (1980)
CI-7	$\frac{\text{ABV (mL)} \times \text{RB}}{\text{RL (cm) + 1RL (cm) + 2RL (cm)}}$	SEPAHI (1980)
CI-8	$\frac{\text{BW (g)} \times \text{RB}}{\text{RL (cm) + 1RL (cm) + 2RL (cm)}}$	SEPAHI (1980)
CI-9	$\frac{\text{[CBV (mL) - ABV (mL)]}}{\text{ABV mL}} \times 100$	SHAVRUKOV *et al.* (2004)
CI-10	BW (g)/BL (cm)	STERNAD-LEMUT *et al.* (2010)
CI-11	BW (g)/MBV (mL)	FERREIRA *et al.* (1987)
CI-12	BW (g)/$[\text{BL (cm)}]^2$	This work
CI-13	ABV (mL)/$[\text{BL(cm)}]^2$	This work
CI-14	$\frac{\text{BB}}{\text{BL (cm) + 1RL (cm) + 2RL (cm)}}$	This work
CI-15	BB/$\sum_{1\text{-}6}$ IL (cm)	This work
CI-16	10.368 + [0.015 x BW (g)] + (0.002 × BB) [-0.443 × BL (cm)] + (0.018 × 1RL)	This work
CI-17	$\frac{\text{BW (g)} \times \text{BB}}{[\text{BL (cm)}]^2 + \text{1RL (cm)}}$	This work
CI-18	$\frac{\text{BW (g)} \times \text{BB} \times (1 + \text{SB})}{[\text{BL (cm)}]^2 \times \text{1RL (cm)} \times \text{PL (mm)}}$	This work
CI-19	$\frac{\text{BW (g)} \times \text{BB} \times (1 + \text{SB})}{[\text{BL (cm)}]^2 \times \text{1RL (cm)} \times \text{RB}}$	This work

[a]: 1RL: First ramification length; 2RL: Second ramification length; ABV: Actual bunch volume; BL: Bunch length; BW: Bunch weight; CBV: Conical bunch volume; IL: Internode length; MBV: Morphological bunch volume; BB: Berries per bunch; RB: Ramifications per bunch; PL: Pedicel length; RL: Rachis length; SB: Seeds per berry.

evaluation panel (reference ranking). Similar rankings were elaborated for each index. Kendall's *Tau-b* correlation coefficient between the places of the 110 bunches in the reference ranking and each index ranking was calculated to determine the ability of the index to preserve the order established by the judges. These rankings were also used to evaluate how many of the 54 bunches included in the first (Q1) and fourth (Q4) quartiles of the reference ranking stayed in such position in the ranking elaborated for the index. In this sense, Q1 included the looser bunches, whilst Q4 included the more compact bunches (but for the CI-9, with negative correlation and opposite relationship).

3. Lastly, continuous values given by each index were transformed to one of five qualitative categories (1, 3, 5, 7 and 9), to allow direct comparison with categories obtained with the visual OIV descriptor. The cut points to establish these categories were determined independently for each index, from the range comprised between the percentiles 5 and 95 of the index values, dividing the extent of the range by 5. Then, bunches with index values comprised between 0 and the first cut point were assigned to category 1, bunches with index values between cut points one and two were assigned to category 3, and so on. CI-9 was coded inversely due to its negative relationship. Once coded, these values were compared to the mode value given by the visual evaluation panel, determining the percentage of coincidence. The number of modified notations was also determined for bunches that did not match with their reference category.

Statistical analyses were performed using SPSS v. 21.0 (Chicago, IL). Results were considered statistically significant at two different levels (0.01 and 0.05).

Results and Discussion

The estimation of bunch compactness is quite controversial. The visual OIV descriptor Nº 204 (O.I.V., 2007), commonly used in different studies, provides a qualitative and subjective information of the trait. The subjectivity linked to this evaluation system is reduced by the use of competent analytical panels formed by trained judges. Nonetheless, this option is not always available, and is unpractical. In the best case, judge panels may only provide categorical data, which have limited utility for certain studies that require a continuous variable.

The usefulness of eleven published indexes to estimate bunch compactness have been tested in this work (Tab. 3, CI-1 to CI-11), using as reference the consensual categorical values obtained from a visual panel to minimize problems linked to subjectivity. These published indexes arise from different mathematical combinations of ten morphological parameters of the bunch: five of them correlated significantly with bunch compactness in our sample (Tab. 4).

Besides, eight new indexes were designed (Tab. 3, CI-12 to CI-19) using eight of the mentioned variables and another three variables which had been pointed out in literature as relevant in the compactness of bunches: the length of the pedicels (Gabler *et al.* 2003), the number of seeds per berry (Bayo-Canha *et al.* 2012) and the length of the first six internodes of the rachis (Shavrukov *et al.* 2004). The length of the pedicels had been pointed out as a factor that may affect bunch compactness because shorter pedicels get the berries closer against each other in the rachis (Gabler *et al.* 2003). Nonetheless, we did not found a significant correlation between this variable and bunch compactness in our sample (Tab. 4), though some degree of variation had been found for the trait (Tab. 1). In a recent study developed in a Monastrell x Syrah F_1 progeny (229 plants), Bayo-Canha *et al.* (2012) marked out the number of seeds per berry as the unique remarkable variable correlating with bunch density (r = 0.31) within a list of twenty-two segregating agronomic traits. Our data support this finding, as this trait showed the second highest correlation coefficient (ρ = 0.377, $p \leq 0.01$) with bunch compactness (Tab. 4). The length of the internodes of the rachis had been pointed out to be the major responsible for inflorescence openness (Shavrukov *et al.* 2004). In agreement with this finding, the sum of the six first internodes of the rachis correlated significantly with bunch compactness in our sample (Tab. 4). Other variables like bunch width, berry length and width, and peduncle length were explored in the initial definition of new indexes, but finally were not included because they did not improve the results obtained.

Table 4

Kendall's *Tau-b* correlation coefficients between the variables included in this study and the mode value of visual compactness given by 14 judges to the 110 bunches studied

Variable	ρ^a
Actual bunch volume	N.S.
Morphological bunch volume	N.S.
Conical bunch volume	-0.208
Bunch weight	N.S.
Bunch length	-0.235
Bunch width	N.S.
Berries per bunch	N.S.
Berry length	N.S.
Berry width	0.254
Seeds per berry	0.377
Rachis weight	N.S.
Ramifications per bunch	0.442
Peduncle length	N.S.
Internode (1^{st}-6^{th}) length	-0.270
First ramification length	-0.292
Second ramification length	-0.308
Pedicel length	N.S.

N.S.: not significant correlation; [a]: coefficients are significant at the 0.01 level.

Several new indexes were designed by modifying those already published, including those variables that might have an important role in bunch compactness, according to our results and published data. Specifically, CI-12 was designed modifying CI-10 (Sternad-Lemut *et al.* 2010), giving a greater weight to the length of the bunch, variable that in our sample correlated significantly ($p \leq 0.01$) with bunch compactness (Tab. 4). CI-13 was designed from CI-12 to evaluate the effect of the substitution of the weight of the bunch by its actual volume. CI-14 was designed including the length of the second ramification of the bunch on the denominator of CI-2 (Valdés-Gómez *et al.* 2008). In our sample, this variable correlated significantly ($p \leq 0.01$) with bunch compactness (Tab. 4). The length of the rachis internodes had been previously pointed out as determinant factors of the bunch density (Shavrukov *et al.* 2004). In this sense, CI-15 was conceived to evaluate their usefulness to predict bunch compactness. CI-16 is the equation of a multiple regression analysis performed with four variables commonly used for the designing of published indexes: bunch weight, number of berries, bunch length and the length of the first ramification of the bunch (data not shown). CI-17 was designed by a mathematical combination of these four variables, including in the numerator variables which tend to increase bunch compactness and in the denominator factors which decrease it. CI-18 was elaborated by adding to the previous combination two variables not considered previously: the number of seeds per berry and the length of the pedicels. CI-18 was modified to create CI-19, substituting the length of the pedicels by the number of ramifications of the rachis, variable with the highest correlation coefficient with bunch compactness according to our results (Tab. 4).

As explained in Material and Methods, all these indexes were evaluated following three criteria and taking as reference those values obtained by a visual evaluation panel of 14 judges who used the OIV descriptor Nº 204. Tab. 5 shows the correlation coefficients for the values obtained with every index and the mode values given by the panel for the 110 bunches. Four indexes did not show a significant correlation. Three of them were found in literature as objective estimators of bunch compactness (CI-3, CI-7 and

Table 5

Correlation coefficients between the mode value of bunch compactness given by the visual evaluation panel and the value obtained for 19 different compactness indexes (CI) to 110 bunches (Kendall's *Tau-b* correlation coefficient)

	ρ
CI-1	0.329**
CI-2	0.273**
CI-3	N.S.
CI-4	0.182*
CI-5	0.356**
CI-6	0.351**
CI-7	N.S.
CI-8	N.S.
CI-9	-0.353**
CI-10	0.279**
CI-11	0.200**
CI-12	0.468**
CI-13	0.435**
CI-14	0.305**
CI-15	N.S.
CI-16	0.507**
CI-17	0.424**
CI-18	0.495**
CI-19	0.556**

N.S.: not significant correlation; *: significant at the 0.05 level, **: significant at the 0.01 level.

CI-8). CI-3 was used for the evaluation of a unique grape variety (Rubi) (POMMER *et al.* 1996), whilst CI-7 and CI-8 were used for the evaluation of bunches of the Yaghouti variety (SEPAHI 1980), so such indexes seem not to be suitable for the evaluation of a wider sample of bunches with a higher morphological diversity. Index CI-15 did not show a significant correlation with the mode visual compactness either. It was designed to evaluate the individual usefulness of the internodes length in the prediction of bunch compactness, variable previously marked out by SHAVRUKOV *et al.* (2004) in a study including four varieties ('Riesling', 'Chardonnay', 'Exotic' and 'Sultana'). Nonetheless, these lengths do not seem to be powerful enough for the objective estimation of bunch compactness in a wider framework. On the other hand, six indexes designed in this work (CI-12, CI-13, CI-16, CI-17, CI-18 and CI-19) obtained better correlation coefficients than the highest coefficient obtained by any of the indexes previously described (CI-5: ρ = 0.356; $p \leq 0.01$). According to these results, these six new indexes are more suitable than published indexes when studying bunch samples of high diversity, like those used in this work.

Following the second criterion of evaluation, bunches were sorted in increasing order for the compactness value, determining then the correlation existing between the rankings obtained for each index and the reference ranking (from visual panel data). Results are indicated in Tab. 6.

The highest value of correlation obtained by a compactness index found in literature (CI-6, ρ = 0.418; $p \leq 0.01$) was overcome by six indexes designed in this work: CI-12, CI-13, CI-16, CI-17, CI-18 and CI-19. Among them, the indexes CI-19 (ρ = 0.618; $p \leq 0.01$), CI-16 (ρ = 0.612; $p \leq 0.01$), CI-18 (ρ = 0.611; $p \leq 0.01$) and CI-12 (ρ = 0.600; $p \leq 0.01$) obtained the highest values of correlation. Furthermore, those indexes obtained the highest number of bunches persisting in the first or fourth quartiles of the ranking of reference, with 38, 39, 38 and 37 bunches satisfying this premise, respectively. These four indexes have also been highlighted in the previous criteria.

According to the third evaluation criterion established, the quantitative values given by the indexes to the 110 bunches were categorized in five ordinal qualitative values (1, 3, 5, 7 and 9). Every categorized value was compared to the mode value of the visual evaluation panel. Taking into account that the variation of two (or more) categories implies strong conceptual changes in the notation given to a bunch (e.g.: from notation 7 "Dense bunch" to notation 3 "Loose bunch"), only the index values which had the same category or varied it in one unique category with respect to the reference were considered acceptable. Results are shown in Fig. 2. Wide differences were observed in the results obtained for each index, with values ranging from 50.0 % (CI-7) to 87.3 % (CI-16) of the index values keeping or changing one category. The highest value obtained corresponded to the index designed according to a multiple regression analysis performed with four variables in this sample, as could be expected. Nevertheless, its usefulness

Table 6

Evaluation of the compactness indexes. Kendall's *Tau-b* correlation coefficients between the ranking obtained with the average values of the visual bunch compactness given by 14 judges and the rankings obtained with the values from 19 different compactness indexes (CI) are shown. The ranking of visual compactness included 27 bunches in the first quartile and 27 bunches in the fourth quartile; Q1 and Q4 indicate, for every index ranking, the number of bunches that stayed in those quartiles respectively

	ρ	Q1	Q4	Q1+Q4
Reference Ranking		27	27	54
Ranking CI-1	0.404**	13	14	27
Ranking CI-2	0.323**	15	11	26
Ranking CI-3	0.151**	10	8	18
Ranking CI-4	0.230**	8	10	18
Ranking CI-5	0.391**	13	15	28
Ranking CI-6	0.418**	13	16	29
Ranking CI-7	0.184**	8	10	18
Ranking CI-8	0.218**	9	11	20
Ranking CI-9	-0.338**	11	15	26
Ranking CI-10	0.408**	14	14	28
Ranking CI-11	0.285**	11	13	24
Ranking CI-12	0.600**	18	19	37
Ranking CI-13	0.539*	19	17	36
Ranking CI-14	0.353**	14	13	27
Ranking CI-15	0.164**	11	10	21
Ranking CI-16	0.612**	21	18	39
Ranking CI-17	0.554**	17	17	34
Ranking CI-18	0.611**	20	18	38
Ranking CI-19	0.618**	20	18	38

*: Significant at the 0.05 level, **: significant at the 0.01 level.

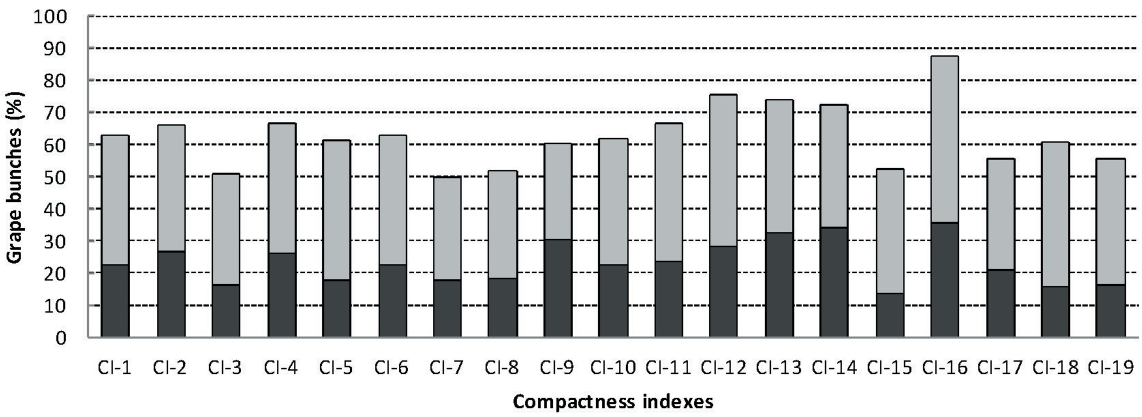

Fig. 2: Percentage of the 110 grape bunches that fit into the same category (■) or change it in one value (■) when comparing the notation given by the visual evaluation panel and the one obtained after recoding into five categories (1, 3, 5, 7, and 9) the value of the compactness indexes (CI).

in its present form in other samples is improbable, because the coefficients are specific for this sample. In this sense it seems to be more useful the use of the index CI-17, equation based on the relationship of the same variables included in such regression analysis.

Other three indexes obtained percentages of persistence over 70.0 %: CI-12, CI-13 and CI-14. CI-12 and CI-13 were highlighted previously, so they seem to be interesting candidates for the objective estimation of bunch compactness. On the other hand, CI-18 and CI-19, highlighted in the previous stages of evaluation did not obtain remarkable results with this criterion, appearing to be sensitive to the stage of categorization. Nevertheless they are still interesting when the aim is to get quantitative data.

CI-12 and CI-13 have constantly appeared in the different stages of evaluation. In this sense, CI-12 showed a direct coefficient of correlation with the value of reference of 0.468 ($p \leq 0.01$), value that increased to 0.600 ($p \leq 0.01$) when analysing the place of the bunches in the rankings. Thirty seven bunches out of 54 maintained their position in the first and fourth quartile defined for the ranking of reference, and 75.23 % of bunches kept or varied in just one value the category of reference. Regarding CI-13, similar values were obtained. The latter was designed from the former, changing the variable bunch weight by the variable actual bunch volume. As the evaluation of the volume of a bunch is a more complex and time-consuming task than the determination of its weight, the use of the index CI-12 is preferred over the use of CI-13.

To assess their applicability beyond this sample of 110 bunches, three selected indexes: CI-12, CI-18 and CI-19, were tested in two larger samples of bunches of different varieties during two consecutive vintages (2011 and 2012, with 1040 and 1145 bunches, respectively). Bunches were morphologically described as explained in material and methods (data not shown) but for cluster compactness, which was generally evaluated by a panel formed by three trained judges. Both years the three indexes correlated significantly with the reference values ($p \leq 0.01$). Using 2011 data, the coefficients of correlation obtained for CI-12, CI-18 and CI-19 were 0.502, 0.597 and 0.538 respectively. In 2012, the coefficients of correlation obtained were even higher (ρ = 0.532, 0.650 and 0.610, for CI-12, CI-18 and CI-19 respectively). The remarkable correlation coefficients obtained suggest that the indexes proposed here are highly suitable candidates for the quantitative and objective estimation of grapevine bunch compactness.

Conclusions

In this work different indexes have been evaluated to determine their usefulness to obtain objective and quantitative estimations of bunch compactness, using a sample of 110 bunches from 11 different varieties of high morphological variability. In general, low applicability was observed for the indexes found in literature in the evaluation of our sample, probably because those indexes were created from the evaluation of a low number of varieties with a narrow diversity for the bunch morphology. Some of the indexes designed here seem to be more interesting when evaluating bunches of different morphology. CI-18 and CI-19 have shown the highest values of correlation with the reference value of compactness and, although they seem to be sensitive to the stage of categorization, they are interesting indexes for the quantitative estimation of bunch compactness in intervarietal studies. These two indexes include the combination of six variables, indicating the high number of factors involved in this complex trait. On the other hand, CI-12 has stood out in all the evaluation criteria used. It is based in the combination of two easy-to-measure characteristics of the bunch (weight and length), so this index is proposed as the simplest one for the estimation of bunch compactness. In this sense, the viticulture sector will find very useful the use of this easy, rapid and non-destructive index to evaluate the compactness of grape bunches.

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