

Morphological Parameters in Grape Bunches and Berries Evaluation through Multivariate Analysis – Case Study on the 'Feteasca Regala' Cultivar

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Abstract. Morphological parameters of grape bunches and grape berries in bunches are important indicators for the yield and quality of grapes and wine products. The study analyzed structural elements of grape bunches and berries, the 'Feteasca Regala' cultivar. The grape samples came from the Recas Viticultural Center. Several parameters were determined: grape bunch weight (GBW, g); four categories of grape berry, normal grape berries (C1), mean/small grape berries (C2), small grape berries (C3), spoiled grape berries (C4) – for each category the number (no), and the weight (w, g). The total berry number of grape (TBnG) was calculated. The rachis weight (RW, g), and must volume (MV, ml) were determined. According to the coefficient of variation, all parameters showed low variability. Very strong, positive correlation was recorded between C4-no and C4-w ($r = 0.934$, ***), and very strong negative correlation was recorded between C1-w and C4-w ($r = -0.922$, ***). Strong, positive correlation was recorded between TBnG and C1-no ($r = 0.816$, ***), between TBnG and C2-no ($r = 0.834$, ***), between C2-no and C2-w ($r = 0.897$, ***). These correlation values showed the high importance of the two categories of grape berries (C1 and C2) in the formation of the TBnG parameter. According to PCA, five parameters were loaded in Factor 1, with very strong action (C1-w, C4-w, C4-no), with strong action (C3-w), and with moderate action (C2-no). In Factor 2, two parameters with strong action (TBnG, C1-no) were grouped. In Factor 3, the RW parameter with strong action was positioned. Correspondence Analysis showed the score values of each parameter in relation to the working Axes, and the distribution of the parameters based on the recorded score.

Keywords: cluster structure, Correspondence Analysis, factor loading, grape berry categories, Multivariate Analysis

INTRODUCTION

The grapevine is a plant closely linked to the history of humanity, with ecological, economic, and symbolic significance (Savo et al., 2016; Limier et al., 2018; Shecori et al., 2022; Vignani and Scali, 2024). Phenotypic parameters in grapevines are important for evaluating crop traits (Liu et al., 2022).

Grapes have a specific anatomical-morphological conformation, which essentially consists of the rachis with different branches and the grape berries (May, 2000). However, there are different types and shapes of grapes, in relation to the high assortment of genotypes (varieties, local populations), as well as an individual differentiation of the bunches (Liu et al., 2022; Meneses et al., 2025).

The compositional structure of grapes also varies in relation to environmental factors, as a result of the "genotype × environment" interaction (Zhang et al., 2015; Meneses et al., 2025).

The water factor, especially the water stress from the previous year, determines variations in the structure of the grapes from the current year (Guilpart et al., 2014; Victorino et al., 2022; Poblete-Echeverria et al., 2025).

The nutritional factor significantly influences the structure of the grape (size, branching of the rachis, compaction, etc.), the number of berries, the size of the berries, their arrangement in the structure of the bunch (Rogiers et al., 2006; Guilpart et al., 2014; Fayziev et al., 2023). The degree of maturation of the vine canes, the content of mineral elements in the vine canes varied in relation to the applied fertilization and the plant-soil relationship (Sala and Blidariu, 2012; Bora et al., 2015). The content of mineral elements in the canes was found to be important for the differentiation of fruit buds, resistance to winter frost, the start of vegetation in spring, yield and grape quality (D'Eusario et al., 2023).

Among the nutrients, nitrogen influenced grape size, the number and size of berries, and grape quality (Guilpart et al., 2014; Verdenal et al., 2021; Visconti et al., 2023). The increase in phosphorus content generated a negative variation in the number of primary clusters in the vine (Mdemba et al., 2025). The number of clusters per plant, and cluster parameters (e.g. cluster weight, 100-grain weight) did not vary significantly with increasing phosphorus rates (Tassinari et al., 2024). Potassium is a mineral element with high content in the vine, with multiple functionality in metabolism, and grape quality (Rogiers et al., 2017; Ciotta et al., 2020). Differentiated contribution of other mineral elements (secondary macroelements, microelements) was recorded in the structure of grape bunches, parameters and quality of grape berries (Kara et al., 2020; Martins et al., 2020; Bredun et al., 2021).

Grape bunch parameters, the structure and quality of grape berries, are also influenced by cultivation technology, grape thinning work and various foliar treatments with biostimulating substances (Afshari-Jafarbigloo et al., 2020; Wang et al., 2022).

The structure of grape clusters is important for resistance and susceptibility to diseases, for yield, composition, and quality of grape berries (Torres-Limas et al., 2024). The size and quality of berries in grape clusters are important parameters in relation to yield and quality of production and have been investigated by different classical methods, through image analysis and modeling (Torres-Limas et al., 2024). Berry size has been considered an important trait and a key factor for determining the composition and quality of some grape varieties (Martin et al., 2022).

This study analyzed the cluster structure of the 'Feteasca Regala' grape cultivar, and used correlation analysis and multivariate analysis to explain the relationship between the categories of cluster structural parameters and the positioning of these parameters in relation to the principal components.

MATERIAL AND METHODS

The study evaluated the structure of the component elements of grapes from the Recas Viticultural Center, Timis County, Romania, figure 1. The biological material was represented by the 'Feteasca Regala' grape cultivar. Random, in the amount of 30 grapes samples, were collected. The study plot had an area of 20 ha, positioned on a sloping land (5 - 8%), with South-East exposure. The viticultural technology was conventional with total mechanization, except for fruiting cuts.

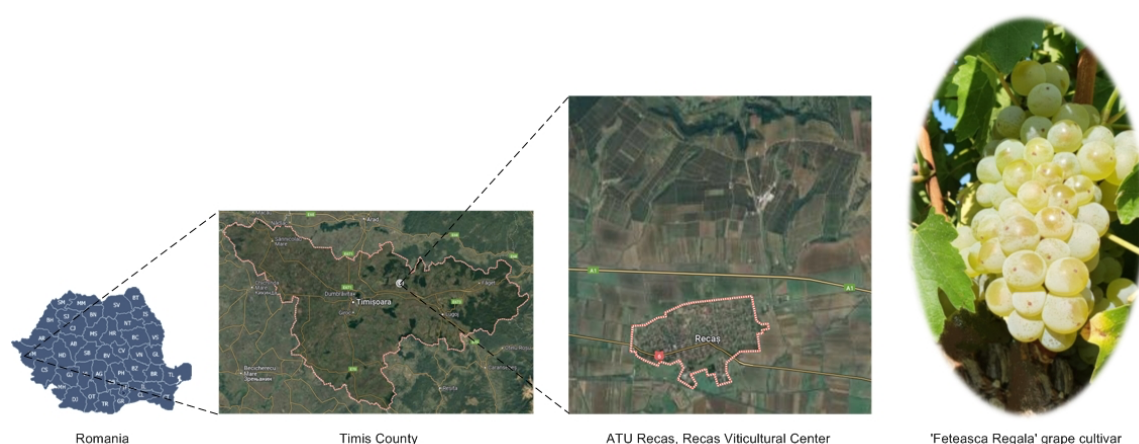


Figure 1. Recas Wine Center, Timis County, Romania (34), 'Feteasca Regala' grape cultivar

For the structural characterization of grapes, a series of parameters were determined. For the individual characterization of grape bunches, grape bunch weight (GBW, g) was determined. For a unitary reference, the total berries number in grape (TBnG, no) was determined, relative to 1 kg of grapes.

Four categories of grape berries were considered: normal grape berries (C1), mean/small grape berries (C2), small grape berries (C3), spoiled grape berries (C4). For each category of berries, the number of berries in the category (C1-no, C2-no, C3-no, C4-no), and the weight of the berries in the respective category (C1-w, C2-w, C3-w, C4-w; g) were determined. The rachis weight (RW, g) and must volume (MV, ml) were determined.

The recorded biometric data were analyzed for general statistical characterization (Descriptive Statistics). The interdependence between parameters was evaluated by correlation analysis (Pearson's correlation), under the conditions of significance thresholds $p < 0.05$ (*), $p < 0.01$ (**), respectively $p < 0.001$ (***).

Multivariate analysis (PCA) was used to obtain the distribution of parameters in relation to the principal components, to find out the intensity and mode of action of the parameters (as factors) in relation to the principal components. Correspondence Analysis (CA) was applied, within the PCA (Hirschfeld, 1935; Benzécri, 1973). In relation to the purpose of the study, PAST software (Hammer et al., 2001) and JASP software (2022) were used.

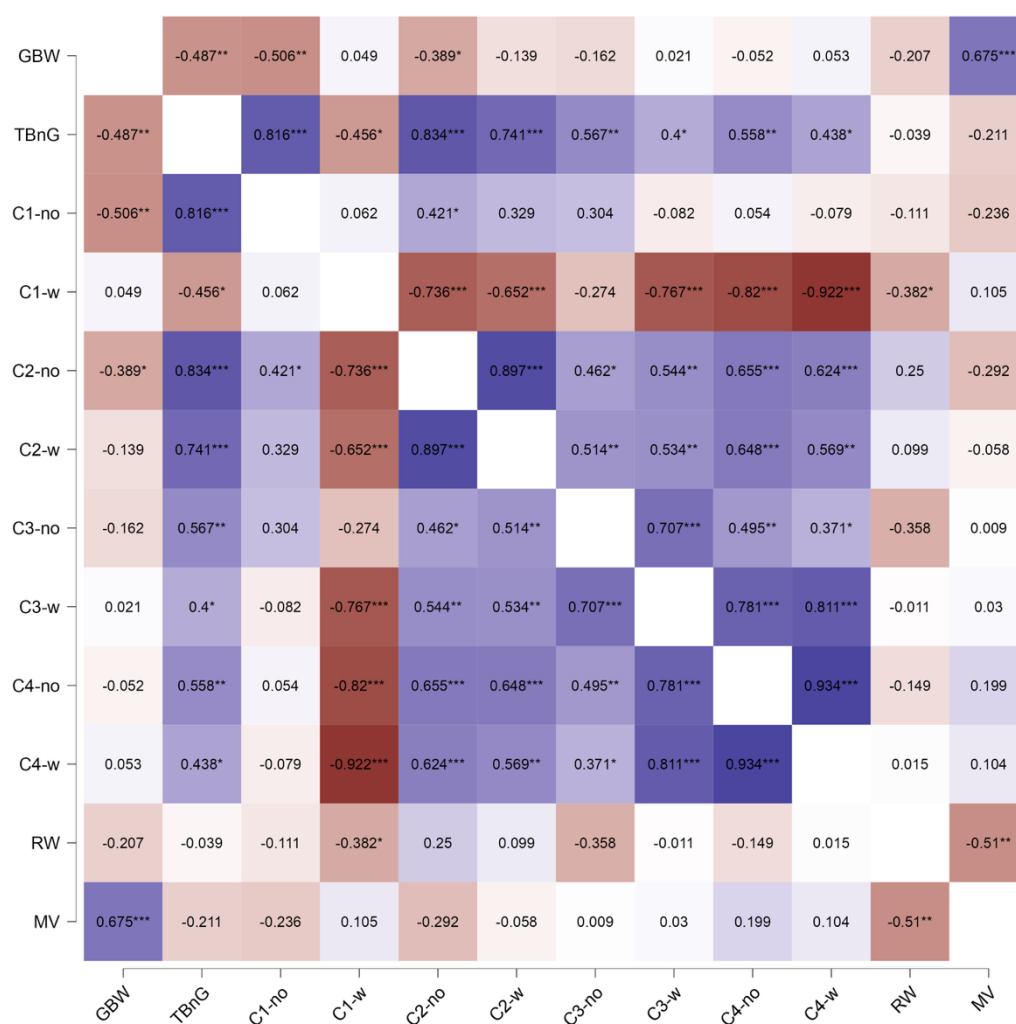
RESULTS AND DISCUSSIONS

The grape samples, the 'Feteasca Regala' cultivar, were analyzed in terms of the constituent elements of the clusters, and the statistical analysis of the data series led to the results in table 1. The data set presented statistical certainty, and the presence of variance was confirmed ($F > F_{crit}$, $p = 0$, Anova Test). According to the values of the coefficient of variation, all parameters presented low variability.

The correlation analysis showed the level of correlation recorded between the parameters considered, with statistical certainty for most cases, figure 2.

Table 1. Values of statistical analysis parameters 'Feteasca Regala' grape cultivar

Parameter	GBW	TBnG	C1-no	C1-w	C2-no	C2-w	C3-no	C3-w	C4-no	C4-w	RW	MV
N	30	30	30	30	30	30	30	30	30	30	30	30
Min	114.00	724.00	609.00	881.80	52.00	11.10	24.00	2.89	32.00	40.60	26.00	680.00
Max	180.00	874.00	680.00	913.60	102.00	15.20	37.00	4.40	60.00	64.00	36.00	784.00
Sum	4428.00	23776.50	19272.00	26997.02	2127.00	395.70	945.00	106.64	1432.50	1548.15	952.50	21948.00
Mean	147.60	792.55	642.40	899.90	70.90	13.19	31.50	3.55	47.75	51.61	31.75	731.60
Std. error	3.16	5.97	3.67	1.42	2.29	0.19	0.54	0.07	1.36	1.14	0.51	4.58
Stand. dev	17.32	32.69	20.10	7.79	12.55	1.05	2.94	0.40	7.46	6.22	2.78	25.06
Median	147.50	793.00	642.25	901.23	69.00	13.38	32.00	3.48	48.00	50.48	32.00	732.25
25 prentil	133.63	774.88	627.00	894.19	61.50	12.50	29.00	3.20	42.00	45.20	30.00	710.50
75 prentil	160.50	809.13	659.50	906.25	76.88	13.81	34.00	3.90	54.63	56.94	34.00	751.00
Skewness	-0.06	0.13	0.01	-0.48	0.75	-0.39	-0.57	0.23	-0.13	0.23	-0.68	-0.06
Kurtosis	-0.60	0.75	-0.95	-0.48	0.30	-0.22	-0.02	-1.02	-0.74	-0.99	-0.48	-0.55
Geom. mean	146.60	791.90	642.10	899.87	69.88	13.15	31.36	3.53	47.17	51.25	31.63	731.18
Coeff. var	11.74	4.13	3.13	0.87	17.70	7.98	9.35	11.23	15.63	12.05	8.75	3.43

**Figure 2.** The level of correlation between grape parameters, 'Feteasca Regala' cultivar

Very strong, positive correlation was recorded at the level of the spoiled grape berries category, respectively between C4-no and C4-w ($r = 0.934$, ***), and very strong negative correlation was recorded between the C1-w and C4-w categories ($r = -0.922$, ***). Strong, positive correlation was recorded between TBnG and C1-no ($r = 0.816$, ***), between TBnG and C2-no ($r = 0.834$, ***), between C2-no and C2-w ($r =$

0.897, ***). These values showed the high importance of the two grain categories (C1 and C2) in the formation of the TBnG parameter. Strong, positive correlation was recorded between the grain categories C3-w and C4-w ($r = 0.811$, ***), and strong negative correlation was recorded between C1-w and C4-no ($r = -0.82$, ***). At the level of other parameters, moderate or low correlation was recorded as an intensity level, within statistical safety conditions.

In relation to the multivariate analysis, parameters considered in the structure of grapes were positioned differently in relation to the main elements, table 2, figure 3. It was observed that five parameters loaded in Factor 1, with very strong negative action C1-w ($r = -0.952$), with very strong positive action C4-w ($r = 0.950$), C4-no ($r = 0.916$), with strong positive action C3-w ($r = 0.845$) and with moderate, positive action, C2-no ($r = 0.718$).

Table 2. Factor Loading

Parameter	Factor 1	Factor 2	Factor 3	Uniqueness
C1-w	-0.952			-0.012
C4-w	0.950			0.094
C4-no	0.916			0.108
C3-w	0.845			0.272
C2-no	0.718			0.098
TBnG		0.880		-0.011
C1-no		0.870		0.239
RW			-0.859	0.242
GBW				0.463
C2-w				0.334
C3-no				0.483
MV				0.408

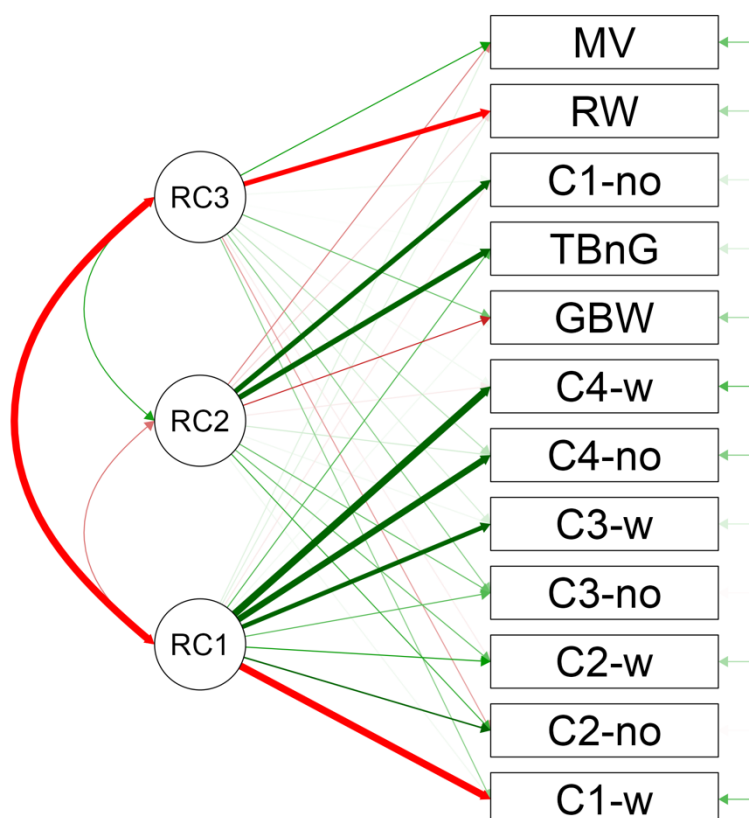


Figure 3. Distribution of grape parameters in the principal factors, 'Feteasca Regala' grape cultivar

In Factor 2, two parameters with strong, positive action were grouped, TBnG ($r = 0.880$) and C1-no ($r = 0.970$). In Factor 3, the parameter RW with strong, negative action was positioned ($r = -0.859$). The

characteristics of the factors are presented in Table 3, with the graphical distribution of the Factor–Eigenvalue interaction in Figure 4.

Table 3. Factor Characteristics

Factor	Unrotated solution			Rotated solution		
	SumSq. Loadings	Proportion var.	Cumulative	SumSq. Loadings	Proportion var.	Cumulative
Factor 1	5.456	0.455	0.455	4.837	0.403	0.403
Factor 2	2.282	0.19	0.645	2.743	0.229	0.632
Factor 3	1.554	0.129	0.774	1.702	0.142	0.774

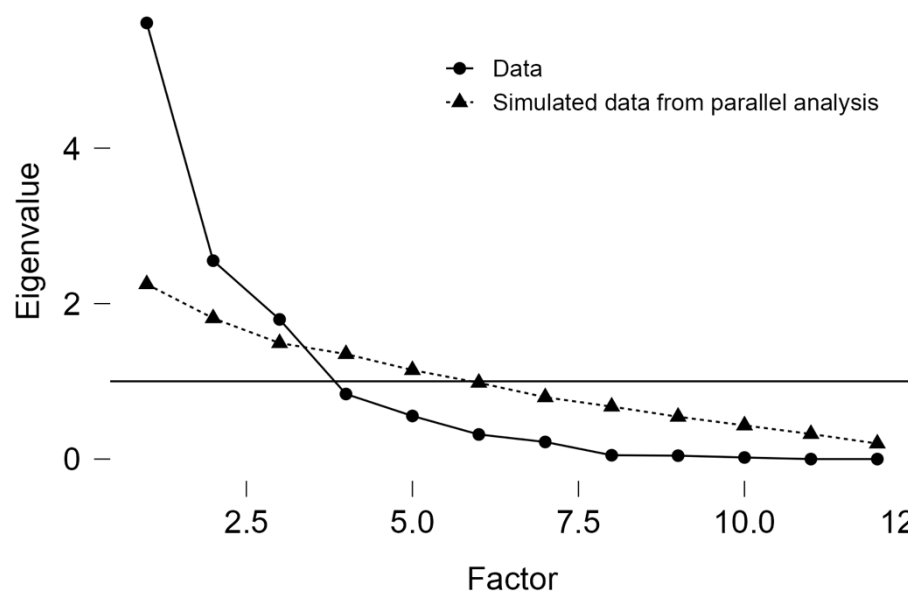


Figure 4. Graphical representation of the Eigenvalue Factor interaction

In the context of multivariate analysis, Correspondence Analysis was used, which led to the data in Table 4 and Table 5. Table 4 presents the Eigenvalue values, their share of the total (%) and the cumulative share (%). High values were observed in relation to the first two axes, Axis 1 and Axis 2.

Table 4. Summary data of Correspondence analysis

Axis	Eigenvalue	% of total	Cumulative
1	0.001321	55.37	55.37
2	0.000635	26.63	82.01
3	0.000172	7.23	89.24
4	0.000114	4.76	94.00
5	6.09E-05	2.55	96.55
6	5.19E-05	2.18	98.73
7	2.02E-05	0.85	99.58
8	7.34E-06	0.31	99.89
9	1.90E-06	0.08	99.97
10	8.42E-07	0.04	100.00
11	1.04E-31	4.38E-27	100.00

Low values were recorded in relation to Axis 3 and Axis 4. The lowest Eigenvalue values were recorded for Axis 5 to Axis 11. The distribution of the parameters in relation to the first two axes, Axis 1 and Axis 2, is presented in the diagram in Figure 5.

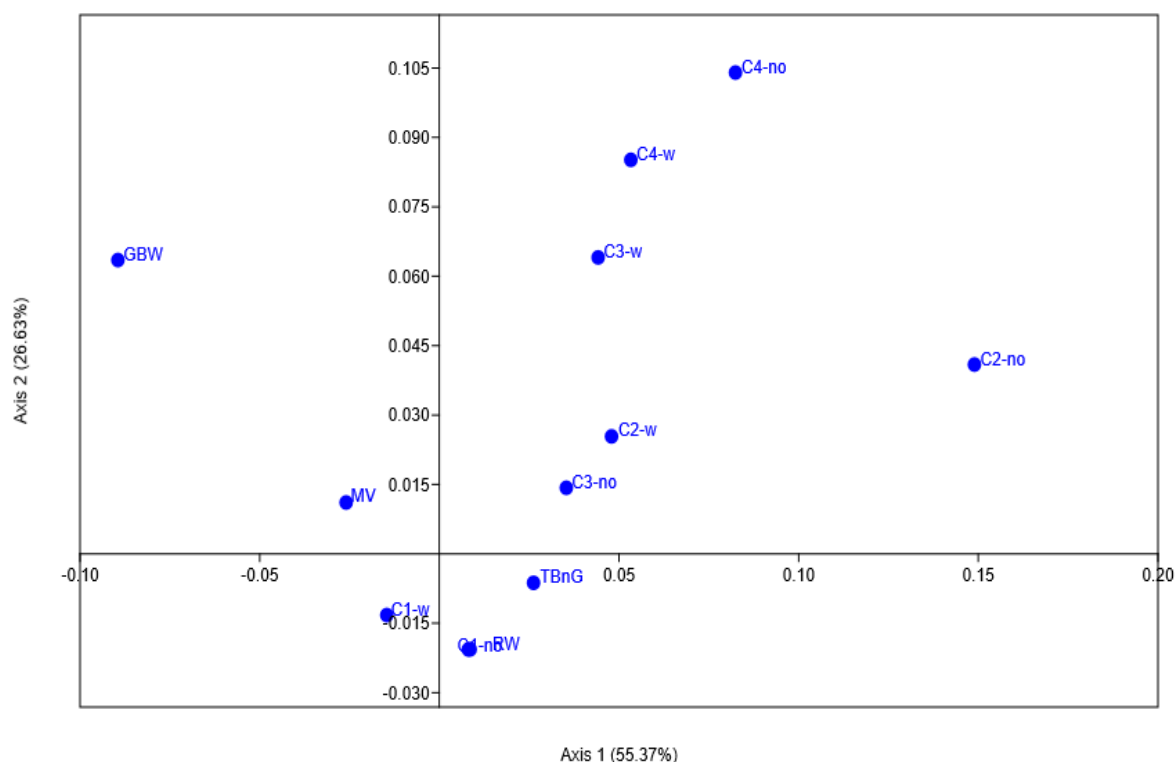


Figure 5. Distribution of parameters in relation to Axis 1 and Axis 2, 'Feteasca regala' grape cultivar

Table 5 presents the score values recorded by each parameter in relation to each axis (Axis 1 to Axis 11), based on Correspondence Analysis. In relation to Axis 1, the highest value was presented by the parameter C2-no (0.14892). In relation to Axis 2, the highest value was presented by the parameter C4-w (0.08516).

Table 5. Parameter score in relation to each axis, grape samples of the 'Feteasca Regala' cultivar

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6	Axis 7	Axis 8	Axis 9	Axis 10	Axis 11
GBW	-0.08946	0.06350	-0.03265	-0.01379	0.00972	-0.00270	0.00111	-0.00148	0.00055	-2.77E-06	-3.19E-16
TBnG	0.02622	-0.00625	-0.00065	-0.00603	0.00218	-0.00263	-0.00092	-0.00034	0.00015	1.39E-05	-3.99E-16
C1-no	0.00805	-0.02066	-0.00047	-0.00647	0.00351	-0.00654	-0.00105	0.00024	-0.00020	-7.46E-05	-2.39E-16
C1-w	-0.01464	-0.01323	0.00029	0.00913	0.00223	0.00541	0.00441	-0.00058	0.00021	-3.22E-05	-3.19E-16
C2-no	0.14892	0.04093	-0.04527	-0.00116	-0.02182	0.01019	0.00658	0.00265	0.00163	-0.00020	-2.39E-16
C2-w	0.04791	0.02539	-0.02283	-0.00764	-0.01327	0.01333	0.00387	-0.01475	-0.02041	5.40E-05	-3.19E-16
C3-no	0.03533	0.01428	0.02053	-0.03485	0.02353	0.05517	-0.01812	0.00191	0.00041	0.00256	-2.39E-16
C3-w	0.04418	0.06407	0.01544	0.01198	0.03710	0.03857	-0.02544	0.01010	-0.00213	-0.02696	-3.19E-16
C4-no	0.08240	0.10401	0.04917	0.01171	0.00582	-0.00725	0.00097	-0.01412	0.00245	-0.00017	-2.39E-16
C4-w	0.05329	0.08516	0.01716	0.02944	0.02389	-0.01026	0.00276	0.01347	-0.00301	0.00129	-3.19E-16
RW	0.00856	-0.02063	-0.05132	0.06731	0.00261	-0.00419	-0.03084	-0.00505	0.00051	0.00098	-3.19E-16
MV	-0.02596	0.01111	0.00899	-0.00030	-0.01116	7.17E-05	-0.00245	0.00124	-0.00011	6.33E-06	-3.19E-16

In relation to Axis 3, the RW parameter presented the highest value, in a negative sense (-0.05132). The RW parameter also presented the highest value in relation to Axis 4 (0.06731). In relation to Axis 5, the C3-w parameter presented the highest value (0.03710).

In relation to Axis 6, the C3-no parameter presented the highest value (0.05517). In relation to Axis 7, again the RW parameter presented the highest value, negative (-0.03084). The C2-w parameter presented the

highest, negative values, in relation to Axis 8 (-0.01475) and in relation to Axis 9 (-0.02041).

In relation to Axis 10, the C3-w parameter presented the lowest value (-0.02696). Within Axis 11, the values were negative, ranging from -2.39E-16 to -3.99E-16.

The graphical representation of the distribution of the parameters, as relay plot is shown in figure 6, according to the scores recorded in Correspondence Analysis.

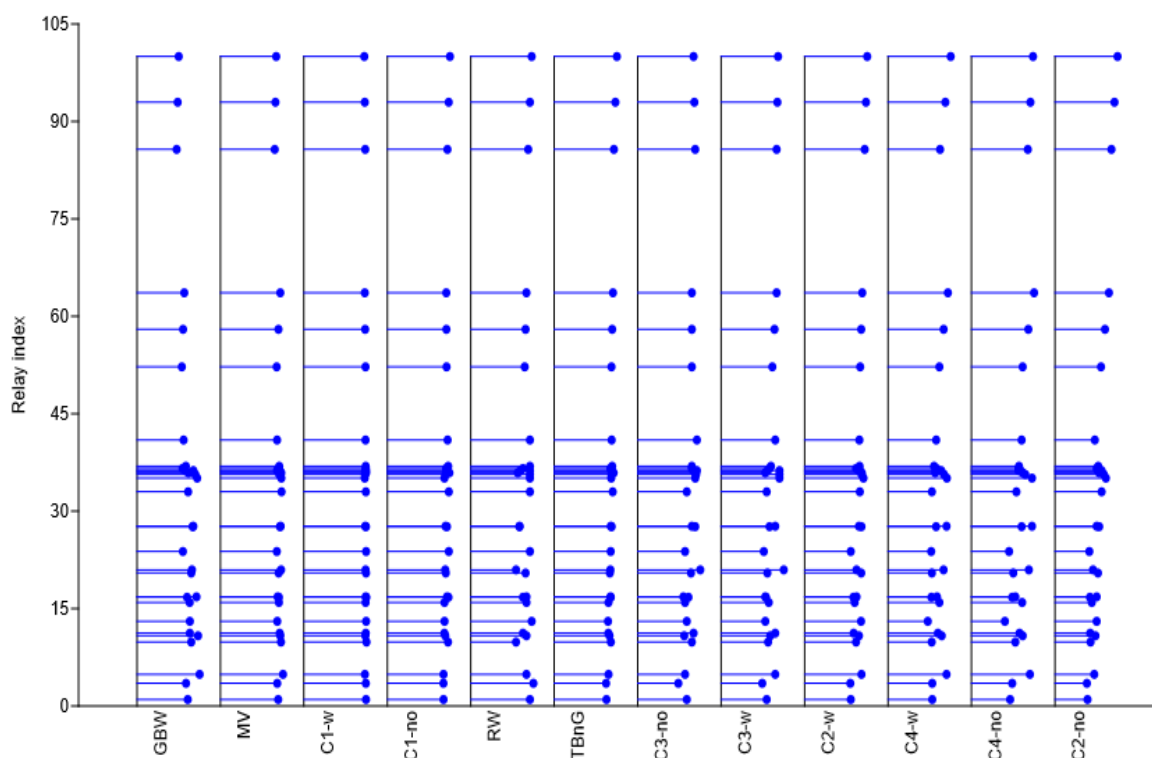


Figure 6. Parameter distribution in relay plot format

New, innovative methods based on "Point Cloud Data" have been used to estimate some parameters in grape clusters (Liu et al., 2022). Image analysis has been promoted to evaluate some properties and characteristics at the grape level (Victorino et al., 2022).

The size and quality of berries in grape clusters, as important parameters in relation to yield and production quality, have been investigated by various classical methods, but also by image analysis and modeling (Torres-Limas et al., 2024).

In 3D phenotyping studies, the results of multivariate analysis suggested that the attributes "bunch length and weight", "berries per bunch", "grape berry weight and diameter" can be considered main descriptors for the degree of grape compaction (Meneses et al., 2025).

Grape berry size has been considered a "key factor" in relation to berry composition and quality in some grape varieties (Martin et al., 2022). Grape bunch structure has been found to be important for the resistance and susceptibility of some grape varieties to diseases, for yield, for grape berry composition and quality (Torres-Limas et al., 2024).

According to PCA under the conditions of the present study, certain parameters regarding the number (C2-no, C4-no) and weight of grape berries (C1-w, C3-w and C4-w) were positioned in PC1, with negative action (C1-w) and positive action of the other four parameters. Parameters TBnG and C1-no were positioned in PC2, with strong positive action. Rachis weight (RW) was positioned in PC3, with a strong negative effect.

Strong, positive correlation was recorded between TBnG and C1-no, between TBnG and C2-no, between C2-no and C2-w. The level of correlation showed the high importance of the two categories of grains (C1 and C2) in the formation of the TBnG parameter

From the Correspondence Analysis, the Eigenvalue values, their share of the total (%) and the cumulative share (%). Also, through Correspondence Analysis, the score values recorded by each parameter in relation to each axis (Axis 1 to Axis 11) were generated. Within each Axis, parameters were identified that presented high values, positive or negative, associated with the activity of the parameters in the respective class.

CONCLUSIONS

Parameters of grape bunches and berries, 'Feteasca Regala' cultivar, presented low variability, according to the values of the coefficient of variation (CV), in conditions of statistical safety of the experimental data and confirmation of the presence of variance in the data set.

Variable correlation, positive and negative, was registered between certain parameters at the level of bunches and grape berry categories. The high level of correlation showed the high importance of the two berry categories (C1 and C2) in the formation of the TBnG parameter.

According to the multivariate analysis, the distribution of parameters in relation to the main factors resulted in five parameters in Factor 1 (C1-w, C4-w, C4-no, C3-w and C2-no), two parameters in Factor 2 (TBnG, C1-no), and one parameter in Factor 3 (RW). The association of parameters TBnG and C1-no in Factor 2, and the strong positive correlation ($r = 0.816$, ***) of the two parameters showed their importance in the formation of yield.

Correspondence Analysis generated the Eigenvalue values, their share of the total (%) and the cumulative share (%) and the score values recorded by each parameter in relation to the working axes (Axis 1 to Axis 11). On each axis, the score values for each parameter were loaded, in relation to their contribution on the axes.

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