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# ANALYSIS OF THE GRAPE BERRIES DISTRIBUTION BY SIZE CATEGORIES IN GRAPE BUNCHES

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***ABSTRACT***
*The distribution of grape berry size categories within the clusters was analyzed in this study. The research was conducted in the Horticultural Didactic Base of the University of Life Sciences "King Mihai I" from Timisoara. Three grape varieties were studied, namely 'Burgund', 'Riesling' and 'Silvania'. The grape berries were analyzed for size and weight structure, based on the following parameters: grape bunch weight (GBW, g), total berries number in grape (TBnG), normal grape berries number (NGB_No), normal grape berries weight (NGB_W), spoiled grape berries number (SpGB_No), spoiled grape berries weight (SpGB_W), mean-smal grape berries number (MSmGB_No), mean-smal grape berries weight (MSmGB_W), small grape berries number (SmGB_No), small grape berries weight (SmGB_W), and rachis weight (RW). High variability was recorded for the parameter SmGB_No, variety 'Silvania' (CV = 42.67). Variable levels of correlation, positive and negative, were recorded between grape berry parameters, in conditions of statistical safety ($p<0.05$). The two main components (PC1, PC2) explained 84.437% of the total variance. Eight parameters were positioned in PC1 and two parameters were positioned in PC2. The NGB_W parameter was positioned independently in relation to the main components, as well as in relation to the other parameters in terms of correlation. Nine parameters showed positive action, and two parameters showed negative action, in relation to the main components.*
**KEY WORDS:** *cluster structure, grapevine, grape berries, PCA, structural distribution*

## INTRODUCTION

Grapevine (*Vitis vinifera* L.) is a plant with a long history and multiple significances in the history of humanity (Terral *et al.*, 2009; Limier *et al.*, 2018; Grassi and Lorenzis, 2021). The grapevine has presented and will always present symbolic, ecological, economic and social importance in people's lives (Savo *et al.*, 2016; Montaigne *et al.*, 2021; Shecori *et al.*, 2022; Frioni *et al.*, 2023). The grapevine includes a large number of cultivated varieties and genotypes, but also in the spontaneous flora, as potential natural resources for breeding programs (Sargolzaei *et al.*, 2021; Shecori *et*

*al.*, 2022; Mian *et al.*, 2023; Boursiquot *et al.*, 2025).

The grapevine includes a wide range of genotypes for wine, for fresh consumption, for raisins, ornamentals, etc., with adaptability to various environmental conditions (Jackson, 2003; Fidelibus *et al*., 2008; Poni *et al*., 2018; Sargolzaei *et al.*, 2021; Berhe and Belew, 2022; Khadatkar *et al.*, 2025). The vine has a specific relationship with the soil and mineral elements, which determine the growth, development of plants, yield and quality of grapes and wine products (Sala and Blidariu, 2012; Savi *et al*., 2019; Yu *et al.*, 2020; Fernandez-Mena *et al.*, 2023; Karn *et al.*, 2024).

Grapes have been considered the "fruit of the vine" since ancient times, and botanically, grapes are a berry (Das and Bhattacharjee, 2020). Grapes have been among the most appreciated and delicate conventional fruits (Venkitasamy *et al.*, 2019; Das and Bhattacharjee, 2020).

A variable number of grape berries are present in the cluster structure, and between 15 and 300 berries have been reported (Das and Bhattacharjee, 2020).

The morphology of grapes and grape berries is primarily associated with the genotype and growth and development is influenced by environmental conditions (soil, climate) but also by cultivation technology or stress factors (Abiri *et al*., 2020; Zhang *et al.*, 2021; Bahar *et al.*, 2024). Morphological and dimensional parameters of grape berries are of interest and have been studied for the characterization of genotypes, as well as in relation to environmental conditions, applied technologies, stress factors, yield and quality indices (Luo *et al*., 2021; Somogyi *et al.*, 2021).

Appropriate imaging analysis methods, mathematical modeling and statistical analysis have been used in various studies to describe and characterize grapes and grape berries in relation to different genotypes, growing conditions, stress factors, composition and certain quality indices (Mirbod *et al.*, 2016; Kupe *et al.*, 2021; Martin *et al.*, 2022; Torres-Lomas *et al*., 2024).

Grape berry variability was analyzed in relation to genetic and anatomical factors that showed influence in grape berry size variation and some estimation models were generated (Houel *et al*., 2013; Melo *et al.*, 2015; Xie *et al.*, 2018; Liu *et al.*, 2022).

The present study analyzed grape berries in terms of dimensional parameters in three grape varieties, 'Burgund', 'Riesling' and 'Silvania', quantified ratios between parameters, interdependence between parameters and the position of parameters in relation to the principal components.

## MATERIAL AND METHOD

The study analyzed the structure of grape berries in clusters of three grape

varieties, 'Burgund', 'Riesling' and 'Silvania'. The observations were carried out within the Horticultural Teaching Base of the University of Life Sciences "King Mihai I" from Timisoara, figure 1.


**Fig. 1. Study location (Google maps)**

The study was conducted between 2011 and 2017. The vineyard was in the first part of its full maturity period, before the decline and deforestation phase. Grape samples were randomly harvested for each variety, in replicates, at harvest maturity (Lorenz *et al.*, 1995). Grape berries were analyzed for size and weight structure, relative to 1 kg of grapes. A series of parameters were determined to characterize the berries of each grape variety: grape bunch weight (GBW, g), total berries number in grape (TBnG), normal grape berries number (NGB_No), normal grape berries weight (NGB_W), spoiled grape berries number (SpGB_No), spoiled grape berries weight (SpGB_W), mean-smal grape berries number (MSmGB_No), mean-smal grape berries weight (MSmGB_W), small grape berries number (SmGB_No), small grape berries weight (SmGB_W), rachis weight (RW). In relation to the purpose of the study, a series of tests were applied, such as Descriptive Statistics, ANOVA Test, Correlation Analysis, and Multivariate Analysis. The PAST software (Hammer *et al.*, 2001), the JASP (2022) software and the calculation module in EXCEL were used.

**RESULTS AND DISCUSSIONS**

Grape samples from the three grape varieties, 'Burgund', 'Riesling', and 'Silvania' were analyzed, in relation to the purpose of the study, to determine grape berry size parameters. The experimental results were initially analyzed for a general statistical characterization (Tables 1, 2, 3), and to find out the presence of variance and the

reliability of the experimental data (Table 4).

The grape berries in the bunch component were analyzed in terms of the level of variability based on the determined parameters.

In the grape variety 'Burgund', high variability was recorded in the case of the SpNB_No parameter (CV = 41.39), moderate variability in the case of the SmGB_W (CV = 20.46), respectively SmGB_No (CV = 22.36) parameters, and low variability in the case of the other descriptive parameters of the berries.

In the 'Riesling' grape variety, moderate variability was recorded for the parameters SmGB_No (CV = 20.41) and SmGB_W (CV = 23.36), and low variability for the other parameters.

**Table 1. Descriptive Statistics data for the 'Burgundy' grape variety**

| Statistical parameters | GBW | TBnG | NGB_No | NGB_W | SpNB_No | SpNB_W | MSmGB_No | MSmGB_W | SmGB_No | SmGB_W | RW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| Min | 154.50 | 518.50 | 458.00 | 893.00 | 20.00 | 37.45 | 16.50 | 4.55 | 13.00 | 2.10 | 21.95 |
| Max | 182.70 | 758.50 | 658.00 | 933.00 | 67.50 | 59.85 | 25.50 | 8.85 | 26.50 | 4.00 | 37.15 |
| Mean | 162.40 | 611.88 | 534.38 | 914.37 | 37.96 | 44.54 | 20.62 | 7.19 | 18.92 | 2.98 | 31.03 |
| Std. error | 2.27 | 19.01 | 17.29 | 3.07 | 4.36 | 1.89 | 0.88 | 0.39 | 1.17 | 0.17 | 1.65 |
| Stand. dev | 8.19 | 68.55 | 62.34 | 11.08 | 15.71 | 6.83 | 3.16 | 1.41 | 4.23 | 0.61 | 5.94 |
| Median | 159.50 | 614.00 | 510.00 | 912.15 | 33.50 | 43.00 | 20.00 | 7.80 | 18.50 | 3.05 | 33.45 |
| 25 prcntil | 156.05 | 552.50 | 488.75 | 907.50 | 22.50 | 39.43 | 18.50 | 6.08 | 15.25 | 2.33 | 24.45 |
| 75 prcntil | 165.75 | 645.25 | 580.00 | 925.50 | 50.00 | 50.53 | 24.00 | 8.25 | 22.50 | 3.35 | 36.18 |
| Skewness | 1.43 | 0.63 | 0.73 | 0.10 | 0.46 | 1.10 | 0.66 | -0.95 | 0.31 | -0.08 | -0.64 |
| Kurtosis | 2.04 | 0.41 | -0.40 | -0.11 | -0.94 | 0.42 | -0.85 | -0.27 | -1.02 | -0.85 | -1.39 |
| Geom. mean | 162.22 | 608.44 | 531.16 | 914.31 | 35.00 | 44.09 | 20.40 | 7.05 | 18.49 | 2.92 | 30.45 |
| Coeff. var | 5.04 | 11.20 | 11.67 | 1.21 | 41.39 | 15.34 | 15.34 | 19.56 | 22.36 | 20.46 | 19.13 |

**Table 2. Descriptive Statistics data for the 'Riesling' grape variety**

| Statistical parameters | GBW | TBnG | NGB_No | NGB_W | SpNB_No | SpNB_W | MSmGB_No | MSmGB_W | SmGB_No | SmGB_W | RW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| Min | 111.15 | 924.00 | 688.00 | 894.50 | 52.50 | 25.70 | 84.50 | 12.80 | 24.50 | 3.70 | 29.75 |
| Max | 121.95 | 1026.50 | 836.00 | 924.85 | 69.50 | 43.50 | 116.00 | 19.10 | 50.50 | 8.00 | 35.80 |
| Mean | 117.19 | 989.58 | 803.85 | 913.38 | 59.96 | 33.95 | 90.88 | 14.22 | 34.88 | 5.18 | 33.18 |
| Std. error | 0.78 | 8.62 | 11.39 | 2.25 | 1.22 | 1.51 | 2.34 | 0.45 | 1.98 | 0.34 | 0.53 |
| Stand. dev | 2.82 | 31.07 | 41.05 | 8.11 | 4.40 | 5.45 | 8.45 | 1.62 | 7.12 | 1.21 | 1.92 |
| Median | 117.55 | 995.50 | 813.50 | 915.15 | 59.00 | 33.55 | 89.00 | 13.80 | 34.00 | 5.05 | 33.25 |
| 25 prcntil | 115.58 | 968.75 | 789.00 | 908.60 | 57.00 | 29.20 | 85.25 | 13.25 | 29.25 | 4.28 | 31.50 |
| 75 prcntil | 119.10 | 1014.25 | 829.75 | 919.93 | 62.25 | 38.63 | 91.25 | 14.70 | 39.75 | 6.10 | 34.78 |
| Skewness | -0.40 | -1.11 | -2.17 | -0.90 | 0.69 | 0.28 | 2.50 | 2.54 | 0.63 | 0.98 | -0.26 |
| Kurtosis | 0.69 | 0.26 | 5.11 | 1.23 | 0.89 | -0.98 | 7.05 | 7.67 | 0.36 | 0.94 | -1.11 |
| Geom. mean | 117.16 | 989.12 | 802.81 | 913.35 | 59.82 | 33.55 | 90.56 | 14.15 | 34.24 | 5.06 | 33.13 |
| Coeff. var | 2.40 | 3.14 | 5.11 | 0.89 | 7.34 | 16.06 | 9.30 | 11.38 | 20.41 | 23.36 | 5.79 |

**Table 3. Descriptive Statistics data for the 'Silvania' grape variety**

| Statistical parameters | GBW | TBnG | NGB_No | NGB_W | SpNB_No | SpNB_W | MSmGB_No | MSmGB_W | SmGB_No | SmGB_W | RW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| Min | 164.00 | 441.00 | 432.00 | 496.95 | 3.00 | 6.60 | 4.00 | 2.25 | 0.50 | 0.40 | 41.50 |
| Max | 193.00 | 490.00 | 471.50 | 942.80 | 9.00 | 19.30 | 9.00 | 4.50 | 3.50 | 1.35 | 46.00 |
| Mean | 180.77 | 457.50 | 444.23 | 905.47 | 5.08 | 10.91 | 6.12 | 3.30 | 2.08 | 0.98 | 43.74 |
| Std. error | 2.19 | 4.25 | 3.65 | 34.06 | 0.52 | 1.13 | 0.42 | 0.18 | 0.25 | 0.08 | 0.40 |
| Stand. dev | 7.90 | 15.33 | 13.17 | 122.80 | 1.87 | 4.08 | 1.53 | 0.66 | 0.89 | 0.28 | 1.45 |
| Median | 181.50 | 456.50 | 443.00 | 941.30 | 4.00 | 9.15 | 6.00 | 3.50 | 2.00 | 1.05 | 43.20 |
| 25 prcntil | 175.75 | 446.25 | 433.25 | 934.83 | 3.75 | 7.80 | 5.00 | 2.85 | 1.25 | 0.80 | 42.65 |
| 75 prcntil | 187.25 | 461.25 | 449.50 | 941.60 | 6.50 | 13.68 | 7.00 | 3.75 | 2.75 | 1.18 | 45.00 |
| Skewness | -0.42 | 1.35 | 1.19 | -3.60 | 1.05 | 1.12 | 0.28 | -0.12 | -0.27 | -0.85 | 0.17 |
| Kurtosis | 0.28 | 1.13 | 0.59 | 12.97 | 0.08 | 0.19 | -0.67 | -0.36 | -0.66 | 0.04 | -1.16 |
| Geom. mean | 180.61 | 457.27 | 444.05 | 894.58 | 4.80 | 10.30 | 5.94 | 3.24 | 1.85 | 0.93 | 43.72 |
| Coeff. var | 4.37 | 3.35 | 2.97 | 13.56 | 36.82 | 37.39 | 25.01 | 19.96 | 42.67 | 29.15 | 3.31 |

**Table 4. ANOVA Test results (**Alpha=0.001)

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 43224164 | 10 | 4322416 | 546.1136 | 6.8E-233 | 3.036218 |
| Within Groups | 3308414 | 418 | 7914.866 | | | |
| Total | 46532579 | 428 | | | | |

In the grape variety 'Silvania', high variability was recorded for the parameters SpNB_No (CV = 36.82), SpNB_W (CV = 37.39), and SmGB_No (CV = 42.67). Moderate variability was recorded for the parameters MSmGB_No (CV = 25.01), and SmGB_W (CV = 29.15). Low variability was recorded for the other parameters.

Several categories of berries were identified in the composition of grape bunches, according to tables 1, 2, and 3. The ratio between the total numbers of berries in the grape bunches and each berry classification category was calculated. The ratio was calculated for both, the number of berries and the weight of the berries.

The mean values of the calculated ratios are presented in table 5, with representation in the Wenn diagram, over the entire data series, in figure 2. Low values of the ratio were found between the total number of berries in grape bunches (TBnG) and the number of normal berries (NGB_No), and these values showed the high proportion of normal berries in the cluster. In the case of the other categories of berries, higher values were obtained, in the tens, hundreds, or higher order, as was the case with the variety 'Silvania' (1038.414±114.410). High values of the calculated ratios indicated a low share of the respective categories of berries in the number, or weight of berries per 1 kg of grapes.

**Table 5. Ratio of berries by category, per 1 kg of grapes**

| Grape varieties | Ratio of berries by numerical category per 1 kg of grapes | | | |
|---|---|---|---|---|
| | TBnG/NGB_No | TBnG/SpNB_No | TBnG/MSmGB_No | TBnG/SmGB_No |
| 'Burgund' | 1.146±0.011 | 18.567±1.941 | 30.258±1.451 | 33.748±2.217 |
| 'Riesling' | 1.233±0.010 | 16.599±0.408 | 10.970±0.272 | 29.457±1.645 |
| 'Silvania' | 1.030±0.002 | 99.621±8.152 | 79.268±5.555 | 289.822±57.412 |
| Grape varieties | Ratio of berries by weight category per 1 kg of grapes | | | |
| | TBwG/NGB_W | TBwG/SpNB_W | TBwG/MSmGB_W | TBwG/SmGB_W |
| 'Burgund' | 1.060±0.002 | 22.185±0.783 | 140.986±9.011 | 338.735±19.411 |
| 'Riesling' | 1.058±0.002 | 29.164±1.201 | 68.663±1.667 | 195.463±10.680 |
| 'Silvania' | 1.017±0.001 | 93.528±8.095 | 285.989±14.740 | 1038.414±114.410 |

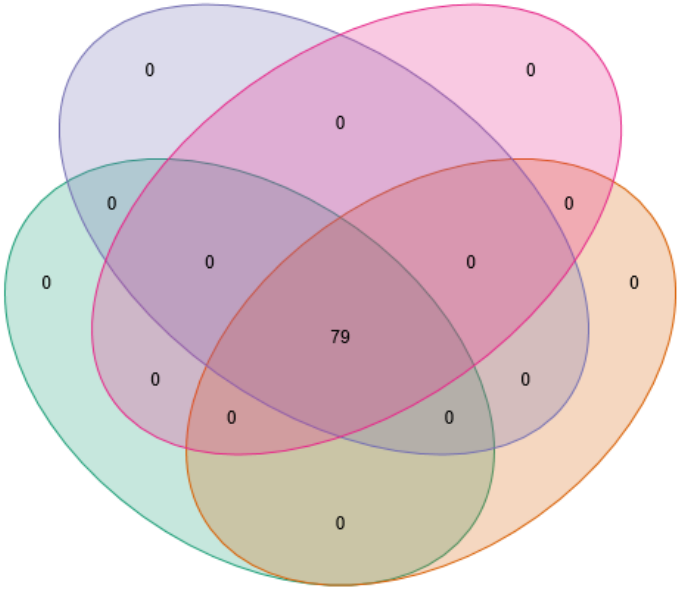


**Fig. 2. Venn diagram based on the calculated ratios between grape berry categories**

The interdependence of grape characterization parameters was quantified by correlation analysis, figure 3.

The GBW parameter recorded a positive correlation with the RW parameter (r = 0.441**) and a negative correlation with the other parameters. The TBnG parameter recorded a negative correlation with the GBW parameter (r = -0.942***) and the RW parameter (r = -0.515***), and a positive correlation with the other parameters. The NGB_No parameter recorded a negative correlation with the GBW parameter (r = -0.914***) and the RW parameter (r = -0.488**) and a positive correlation with the other parameters.

The NGN_W parameter presented an independent position compared to the other parameters, the correlation coefficient values being very low.

The multivariate analysis showed the positioning of the three varieties of grapes in relation to the determined parameters, figure 4. The first two principal components explained 84.437% of the total variance. The independent positioning of the three grape varieties was observed, in different PCA diagram quadrants.

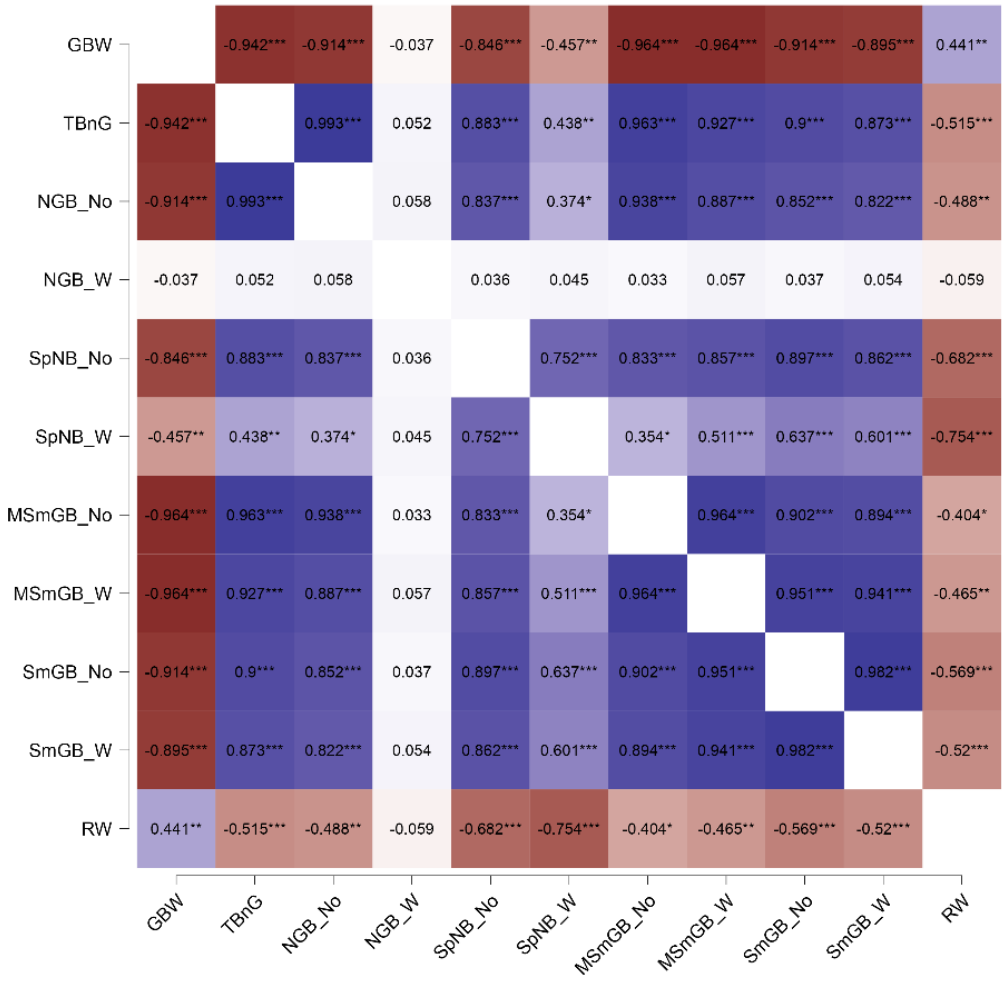


**Fig. 3. Correlation matrix between parameters in grape berries**

Within the PCA, Chi-squared Test led to Model value = 759.437, df = 34, and $p<0.001$. Parameters considered for the characterization of grape berries by size, within the grape samples, were positioned differentially in the principal components, according to table 6, figure 5.

Eight parameters were positioned in PC1. The GBW parameter was positioned

with negative action (r = -0.958), and the other parameters were positioned with positive action. Four parameters showed very strong positive action, r = 0.986 (MSmGB_No), r = 0.955 (TBnG), r = 0.947 (MSmGB_W), and r = 0.939 (NGB_No). Two parameters showed strong action, r = 0.884 (SmGB_No), r = 0.878 (SmGB_W), and one parameter showed moderate action, r = 0.781 (SpNB_No).

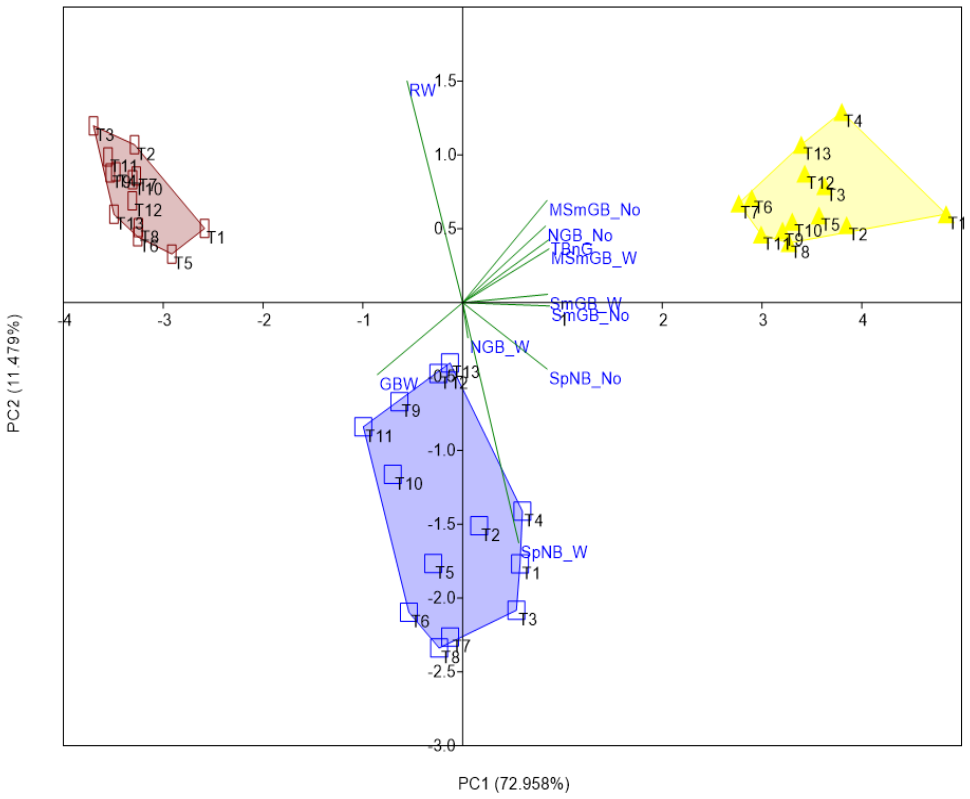


**Fig. 4. PCA diagram with genotype distribution; blue color - 'Burgund' variety, yellow color - 'Riesling' variety, brown color - 'Silvania' variety**

**Table 6. Component loadings**

| Parameters | PC1 | PC2 | Uniqueness |
|---|---|---|---|
| MSmGB_No | 0.986 | | 0.017 |
| GBW | -0.958 | | 0.047 |
| TBnG | 0.955 | | 0.041 |
| MSmGB_W | 0.947 | | 0.043 |
| NGB_No | 0.939 | | 0.09 |
| SmGB_No | 0.884 | | 0.056 |
| SmGB_W | 0.878 | | 0.097 |
| SpNB_No | 0.781 | | 0.071 |
| SpNB_W | | 0.911 | 0.091 |
| RW | | -0.859 | 0.174 |
| NGB_W | | | 0.986 |

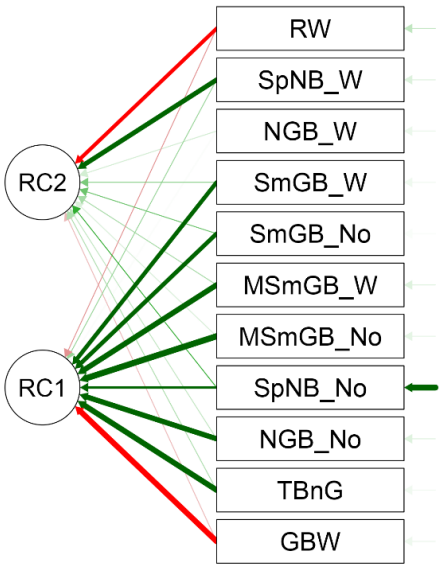


**Fig. 5. Loading parameters onto the main components**

In PC2, two parameters were positioned, with a very strong positive action, the SpNB_W parameter (r = 0.911), and with a strong negative action, the RW parameter (r = -0.859).

The NGB_W parameter positioned itself independently, with very strong action (r = 0.986). The NGB_W parameter presented an independent position compared to the other parameters also in the case of correlation analysis, when the correlation coefficient values were very low.

## CONCLUSIONS

The three grape varieties studied two wine varieties (‘Burgund, ‘Riesling’ and one variety for fresh consumption ('Silvania') presented differentiated values of the characterization parameters of the berries in grape bunches.

Most of the grape berry characterization parameters showed low variability. High variability was recorded in the 'Burgund' variety, the SpNB_No parameter (CV = 41.39) and in the 'Silvania' variety, the SpNB_No parameters (CV = 36.82), SpSB_W (CV = 37.39) and SmGB_No (CV = 42.67). The 'Riesling' variety showed low and moderate variability (two parameters), which showed a higher uniformity of the grape berries in this variety.

The calculated ratios between the TBnG parameter (total number of grape berries) and parameters by berry size category (numerical and weight) showed the participation of berries by category in the formation of grape yield. Large berries, which have higher quality indices, are of high importance.

Multivariate analysis classified grape berries characterization parameters by size categories, in relation to the principal components, identified the mode of action (positive or negative) and the intensity of action of the parameters.

Correlation analysis and multivariate analysis showed the interdependence of grape berry size parameters, and their mode of action in the overall structure of grape bunches, in the studied grape varieties.

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