

Comparative analysis of grape cultivars based on leaf geometry fractal parameters

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Abstract

The study comparatively analyzed seven grape cultivars based on some parameters of the fractal geometry of the leaf lamina. The following grape cultivars were considered in the study: Cabernet Sauvignon (CS), Chasselas (Ch), Muscat Hamburg (MH), Muscat Iantarnii (MI), Muscat Ottonel (MO), Perlă de Csaba (PC), and Victoria (Vi). Through the fractal analysis (box-counting) the parameters D1, D2, BW, B+BW, and W+BW were obtained. The ANOVA test was used for the comparative analysis between the seven grape varieties, based on the values of each fractal parameter. The comparative analysis based on the D1 parameter led to four statistically guaranteed differences ($p < 0.05$). Based on the B+BW parameter, there were differences in conditions of $p < 0.001$ in the case of five comparative analyses, respectively in conditions of $p < 0.01$ in the case of one comparative analysis. Based on the BW parameter, there were statistically guaranteed differences at the level of $p < 0.05$ in the case of one comparison, at the level of $p < 0.01$ in the case of three comparative analyses, and respectively at the level of $p < 0.001$ in the case of two comparisons. Based on the W+BW parameter, there were differences in terms of statistical safety in the case of the 14 comparative analyses; three comparative analyzes at the $p < 0.05$ significance level, one comparison at the $p < 0.01$ level, and ten comparisons at the $p < 0.001$ level, respectively. In the case of D2 parameter, the comparative analysis led to results without statistical certainty.

Keywords: box-counting, comparative analysis, fractal geometry, grapevine cultivars, leaf lamina

Introduction

The grapevine is an ancient cultural plant, with extensive documentation, and a rich representativeness through textual content, iconography, archaeological, archaeobotanical, paleobotanical, morphometric, symbolism, etc. [23], [13], [4].

Grapevine shows a high plasticity, with a very large range of genotypes and phenotypes [7], [6]. The authors studied different phenotypes in relation to the vine crop environment conditions. Based on the recorded results, the authors of the study associated genes potentially involved in the phenotypic plasticity of grapevine in different viticultural systems.

The characteristics of the leaves were studied by fractal analysis, by evaluating the perimeter and venation of the leaves (nerves at the level of the leaf lamina), in order to recognize and classify different plant species [8]. Agapie et al (2020) [1] used fractal analysis to study leaves of soybean genotypes, and the fractal values differentiated the genotypes considered ($p < 0.001$).

Plant phenotyping combines different methods and working protocols to measure certain defining traits of plants, at different levels and scales of organization [6]. Manual phenotyping presents certain constraints, so high-throughput phenotyping methods have been promoted for large series of plane samples. Such methods are mainly based on imaging analysis. Such methods have been studied in relation to the possibility of their application in grape phenotyping [6].

The grapevine (*Vitis vinifera*) is a plant species with multiple values (ecological, economic, social), with

a very high frequency of cultivation, and highly appreciated for the products it provides [22]. The authors of the study evaluated the Georgian germplasm, in relation to the European one, and highlighted certain advantages in terms of diversity, the relationship with environmental factors, tolerance to stress factors, and the quality of genetic resources in relation to climate changes.

Phenology, indices and physiological processes, and grapevine yield were studied in relation to climate variability [18]. The authors recorded variations of the physiological indices, of some physiological processes, biometric parameters at the foliar level, in a differentiated way for the studied genotypes. Based on the results, the authors suggested the need for accessible formulas for extensive vineyard management strategies in relation to environmental changes. Within these strategies, certain indices and physiological (foliar) parameters find an important place, as references for different cultivated genotypes.

Vishnu and Jaishanker (2023) [26] considered important indices and parameters that can express the complex shape in different plant species. The authors considered segmented fractal complexity as an approach that presents advantages in the study of the leaf lamina in plants.

Phenotypic plasticity in the grapevine has been studied in relation to environmental factors and has been associated with epigenetic changes in response to the genotype-environment interaction [25].

The present study comparatively analyzed several grapevine cultivars, based on descriptive parameters of the fractal geometry of the leaves.

Material and Method

The study comparatively analyzed seven cultivars of grapevine based on the leaf typology, quantified by parameters of the fractal geometry of the leaves. The biological material was represented by seven vine cultivars: Cabernet Sauvignon (CS), Chasselas (Ch), Muscat Hamburg (MH), Muscat Iantarnii (MI), Muscat Ottonel (MO), Perlă de Csaba (PC), and Victoria (Vi).

Twenty leaves from each cultivar were taken at random. The leaves were taken from the middle area of the shoots (fully developed leaves). The leaves were herborized immediately after sampling, to keep the shape of the leaves intact. The petiole of the leaves was removed. The leaves were scanned without the petiole, at a scale of 1:1. Digital images of leaf samples resulted, 15 leaves for each cultivar. Figure 1 shows representative leaf shapes for the grape cultivar studied. The images are presented in binarized format.

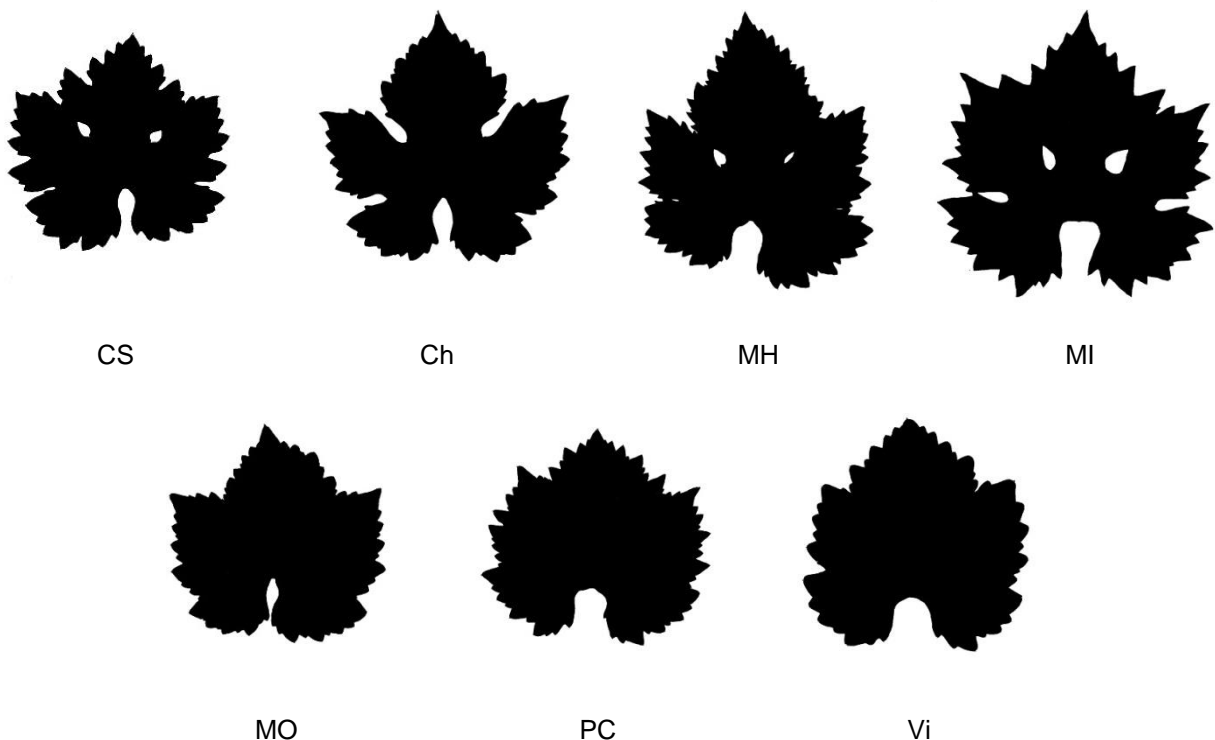


Figure 1. Grapevine leaves from the studied grape cultivars: CS (Cabernet Sauvignon), Ch (Chasselas), MH (Muscat Hamburg), MI (Muscat Iantarnii), MO (Muscat Ottonel), PC (Perlă de Csaba), Vi (Victoria); Original figure, leaves scanned and processed by Florin Sala

To characterize the fractal geometry of the leaves, the following parameters were determined: D1 (MEE = 0.50; MEE – minimize edge effects), D2 (MEE = 0.20), BW (black and white), B+BW (black + black and white), W+ BW (white + black and white).

The digital images, in binarized format, were analyzed to obtain fractal geometry parameters considered in the study. The box-counting method was used [27], [19], [5], [17].

For the comparative analysis of the seven grapevine cultivars, based on the considered fractal geometry parameters, appropriate mathematical and statistical analysis tools were used [10], [11].

Results and Discussion

The analysis of the data series, for the parameters considered in the description of the leaves fractal geometry of the seven vine cultivars, led to the graphic representation in figure 2. The distribution of values is presented in box-plot format, with the representation of the confidence interval (95%). Little variation was found in the case of the D1 and D2 parameters, and wide variation was found in the case of the BW parameter.

The comparative analysis between the seven grape cultivars was done based on the series of data related to each parameter. The results are the presented in tables 1 to table 5.

In the case of the comparative analysis based on the values of the D1 parameter (table 1), statistically significant differences were recorded when comparing CS with MH, CS with MI, CS with MO, and CS with Vi ($p < 0.05$, *). In the case of the other comparisons between cultivars, based on the D1 values, the recorded results did not show statistical certainty, table 1.

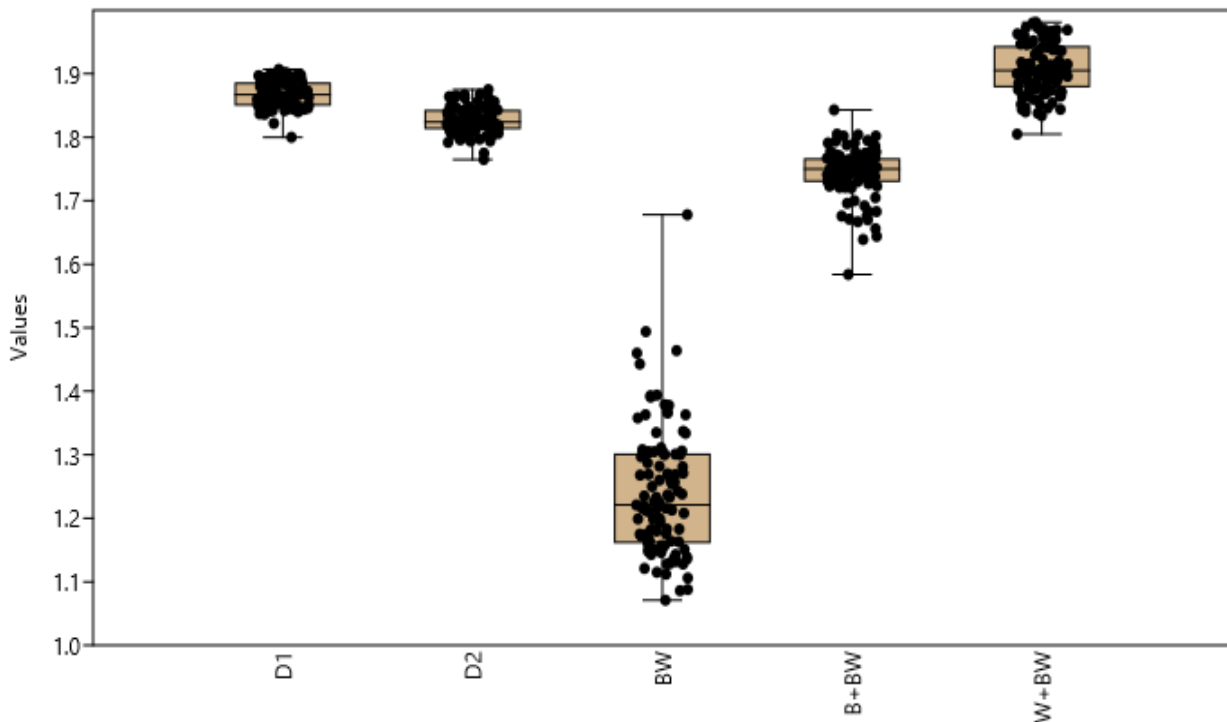


Figure 2. The graphic representation, box-plot format, of the data series for the fractal parameters of the leaves of the grape cultivars studied (original figure)

In the case of the comparative analysis between the seven grape cultivars, based on the D2 parameter values (table 2), the recorded results did not show statistical certainty ($p > 0.05$).

In all the combinations of the comparative analysis of the grapevine cultivars, the statistical safety parameter ($p > 0.05$) did not confirm the safety for the differences recorded between the average values of the D2 parameter.

Table 1. Comparative analysis of grape cultivars based on D1 parameter

Grapevine cultivars and differences		95% CI for Mean Difference			Statistical parameters			
Cultivars		Mean Difference	Lower	Upper	SE	t	P _{tukey}	
CS	Ch	-0.015	-0.041	0.011	0.008	-1.946	0.485	
	MH	-0.029	-0.055	-0.002	0.008	-3.715	0.029	*
	MI	-0.027	-0.054	-8.898×10 ⁻⁴	0.008	-3.53	0.041	*
	MO	-0.029	-0.055	-0.002	0.008	-3.72	0.029	*
	PC	-0.024	-0.05	0.003	0.008	-3.064	0.092	
	Vi	-0.03	-0.057	-0.004	0.008	-3.944	0.019	*
Ch	MH	-0.014	-0.04	0.013	0.008	-1.769	0.586	
	MI	-0.012	-0.039	0.014	0.008	-1.584	0.694	
	MO	-0.014	-0.04	0.013	0.008	-1.774	0.584	
	PC	-0.009	-0.035	0.018	0.008	-1.118	0.912	
	Vi	-0.015	-0.042	0.011	0.008	-1.998	0.456	
MH	MI	0.001	-0.025	0.028	0.008	0.186	1	
	MO	-3.333×10 ⁻⁵	-0.026	0.026	0.008	-0.004	1	
	PC	0.005	-0.021	0.031	0.008	0.652	0.993	
	Vi	-0.002	-0.028	0.025	0.008	-0.229	1	
MI	MO	-0.001	-0.028	0.025	0.008	-0.19	1	
	PC	0.004	-0.023	0.03	0.008	0.466	0.999	
	Vi	-0.003	-0.03	0.023	0.008	-0.414	0.999	
MO	PC	0.005	-0.021	0.031	0.008	0.656	0.993	
	Vi	-0.002	-0.028	0.025	0.008	-0.224	1	
PC	Vi	-0.007	-0.033	0.02	0.008	-0.88	0.97	

Table 2. Comparative analysis of grape cultivars based on D2 parameter

Grapevine cultivars and differences		95% CI for Mean Difference			Statistical parameters			
Cultivars		Mean Difference	Lower	Upper	SE	t	P _{tukey}	
CS	Ch	0.006	-0.026	0.039	0.01	0.637	0.994	
	MH	-0.008	-0.04	0.024	0.01	-0.841	0.976	
	MI	-0.005	-0.038	0.027	0.01	-0.557	0.997	
	MO	-0.019	-0.051	0.014	0.01	-1.982	0.465	
	PC	-0.008	-0.041	0.024	0.01	-0.844	0.975	
	Vi	-0.008	-0.041	0.024	0.01	-0.879	0.97	
Ch	MH	-0.014	-0.047	0.018	0.01	-1.478	0.753	
	MI	-0.011	-0.044	0.021	0.01	-1.194	0.885	
	MO	-0.025	-0.057	0.008	0.01	-2.62	0.192	
	PC	-0.014	-0.047	0.018	0.01	-1.482	0.751	
	Vi	-0.014	-0.047	0.018	0.01	-1.517	0.732	
MH	MI	0.003	-0.03	0.035	0.01	0.284	1	
	MO	-0.011	-0.043	0.022	0.01	-1.142	0.904	
	PC	-3.333×10 ⁻⁵	-0.033	0.032	0.01	-0.004	1	
	Vi	-3.667×10 ⁻⁴	-0.033	0.032	0.01	-0.039	1	
MI	MO	-0.014	-0.046	0.019	0.01	-1.426	0.78	
	PC	-0.003	-0.035	0.03	0.01	-0.287	1	
	Vi	-0.003	-0.036	0.029	0.01	-0.322	1	
MO	PC	0.011	-0.022	0.043	0.01	1.138	0.905	
	Vi	0.01	-0.022	0.043	0.01	1.103	0.917	
PC	Vi	-3.333×10 ⁻⁴	-0.033	0.032	0.01	-0.035	1	

Table 3. Comparative analysis of grape cultivars based on BW parameter

Grapevine cultivars and differences		95% CI for Mean Difference			Statistical parameters			
Cultivars		Mean Difference	Lower	Upper	SE	t	P _{Tukey}	
CS	Ch	0.157	0.033	0.28	0.036	4.329	0.01	**
	MH	0.116	-0.008	0.239	0.036	3.196	0.074	
	MI	0.066	-0.058	0.189	0.036	1.82	0.557	
	MO	-0.092	-0.216	0.031	0.036	-2.554	0.212	
	PC	0.044	-0.079	0.168	0.036	1.225	0.873	
Ch	Vi	0.097	-0.026	0.221	0.036	2.692	0.171	
	MH	-0.041	-0.164	0.083	0.036	-1.133	0.907	
	MI	-0.091	-0.214	0.033	0.036	-2.509	0.227	
	MO	-0.249	-0.372	-0.125	0.036	-6.883	< .001	***
	PC	-0.112	-0.236	0.011	0.036	-3.104	0.086	
MH	Vi	-0.059	-0.183	0.064	0.036	-1.636	0.664	
	MI	-0.05	-0.173	0.074	0.036	-1.376	0.805	
	MO	-0.208	-0.331	-0.084	0.036	-5.75	< .001	***
	PC	-0.071	-0.195	0.052	0.036	-1.971	0.471	
	Vi	-0.018	-0.142	0.105	0.036	-0.503	0.998	
MI	MO	-0.158	-0.282	-0.035	0.036	-4.374	0.009	**
	PC	-0.021	-0.145	0.102	0.036	-0.595	0.996	
	Vi	0.032	-0.092	0.155	0.036	0.873	0.971	
MO	PC	0.137	0.013	0.26	0.036	3.779	0.026	*
	Vi	0.19	0.066	0.313	0.036	5.247	0.002	**
PC	Vi	0.053	-0.07	0.177	0.036	1.467	0.758	

Table 4. Comparative analysis of grape cultivars based on B+BW parameter

Grapevine cultivars and differences		95% CI for Mean Difference			Statistical parameters			
Cultivars		Mean Difference	Lower	Upper	SE	t	P _{Tukey}	
CS	Ch	-0.065	-0.103	-0.027	0.011	-5.829	< .001	***
	MH	-0.094	-0.132	-0.056	0.011	-8.419	< .001	***
	MI	-0.08	-0.118	-0.041	0.011	-7.114	< .001	***
	MO	-0.065	-0.104	-0.027	0.011	-5.846	< .001	***
	PC	-0.059	-0.097	-0.021	0.011	-5.304	0.002	**
	Vi	-0.082	-0.12	-0.044	0.011	-7.358	< .001	***
Ch	MH	-0.029	-0.067	0.009	0.011	-2.591	0.201	
	MI	-0.014	-0.053	0.024	0.011	-1.285	0.848	
	MO	-2.000×10 ⁻⁴	-0.038	0.038	0.011	-0.018	1	
	PC	0.006	-0.032	0.044	0.011	0.525	0.998	
	Vi	-0.017	-0.055	0.021	0.011	-1.529	0.725	
MH	MI	0.015	-0.024	0.053	0.011	1.306	0.839	
	MO	0.029	-0.009	0.067	0.011	2.573	0.206	
	PC	0.035	-0.003	0.073	0.011	3.116	0.085	
	Vi	0.012	-0.026	0.05	0.011	1.061	0.93	
MI	MO	0.014	-0.024	0.052	0.011	1.267	0.856	
	PC	0.02	-0.018	0.058	0.011	1.81	0.563	
	Vi	-0.003	-0.041	0.035	0.011	-0.244	1	
MO	PC	0.006	-0.032	0.044	0.011	0.543	0.998	
	Vi	-0.017	-0.055	0.021	0.011	-1.512	0.734	
PC	Vi	-0.023	-0.061	0.015	0.011	-2.054	0.426	

Table 5. Comparative analysis of grape cultivars based on W+BW parameter

Grapevine cultivars and differences		95% CI for Mean Difference		Statistical parameters				
Cultivars		Mean Difference	Lower	Upper	SE	t	p_{Tukey}	
CS	Ch	0.071	0.046	0.097	0.008	9.470	< .001	***
	MH	0.098	0.072	0.123	0.008	13.002	< .001	***
	MI	0.090	0.064	0.116	0.008	11.947	< .001	***
	MO	0.022	-0.003	0.048	0.008	2.978	0.107	
	PC	0.051	0.026	0.077	0.008	6.816	< .001	***
Ch	Vi	0.082	0.056	0.107	0.008	10.848	< .001	***
	MH	0.027	8.828×10^{-4}	0.052	0.008	3.532	0.041	*
	MI	0.019	-0.007	0.044	0.008	2.477	0.239	
	MO	-0.049	-0.075	-0.023	0.008	-6.492	< .001	***
	PC	-0.020	-0.046	0.006	0.008	-2.654	0.182	
MH	Vi	0.010	-0.015	0.036	0.008	1.378	0.804	
	MI	-0.008	-0.034	0.018	0.008	-1.055	0.931	
	MO	-0.075	-0.101	-0.050	0.008	-10.024	< .001	***
	PC	-0.047	-0.072	-0.021	0.008	-6.186	< .001	***
	Vi	-0.016	-0.042	0.009	0.008	-2.154	0.376	
MI	MO	-0.067	-0.093	-0.042	0.008	-8.969	< .001	***
	PC	-0.039	-0.064	-0.013	0.008	-5.132	0.002	**
	Vi	-0.008	-0.034	0.017	0.008	-1.099	0.918	
MO	PC	0.029	0.003	0.055	0.008	3.838	0.023	*
	Vi	0.059	0.034	0.085	0.008	7.870	< .001	***
PC	Vi	0.030	0.005	0.056	0.008	4.033	0.016	*

In the case of the analysis based on the values of the BW parameter (table 3), statistically significant differences were recorded when comparing CS with Ch ($p < 0.01$, **), when comparing Ch with MO ($p < 0.001$, ***), when comparing MH with MO ($p < 0.001$, ***), when comparing MI with MO ($p < 0.01$, **), when comparing MO with PC ($p < 0.05$, *), and respectively when comparing MO with Vi ($p < 0.01$, **). In the case of the other comparisons between the grapevine cultivars, based on the BW values, the differences did not show statistical certainty ($p > 0.05$), table 3.

In the case of the analysis based on the values of the B+BW parameter (table 4), there were statistically significant differences only when comparing CS with the other cultivars, respectively the comparative analysis of CS with Ch ($p < 0.001$, ***), the comparative analysis of CS with MH ($p < 0.001$, ***), comparative analysis of CS with MI ($p < 0.001$, ***), comparative analysis of CS with MO ($p < 0.001$, ***), comparative analysis of CS with PC ($p < 0.01$, **), and respectively the comparative analysis of CS with Vi ($p < 0.001$, ***). In the case of the other comparisons between the grapevine cultivars, based on the B+BW values, the differences did not show statistical certainty ($p > 0.05$), table 4.

In the case of the analysis based on the W+BW parameter values (table 5), statistically significant differences were recorded when comparing CS with Ch ($p < 0.001$, ***), when comparing CS with MH ($p < 0.001$, ***), when comparing CS with MI ($p < 0.001$, ***), when comparing CS with PC ($p < 0.001$, ***), when comparing CS with Vi ($p < 0.001$, ***), when comparing Ch with MH ($p < 0.05$, *), when comparing Ch with MO ($p < 0.001$, ***), when comparing MH with MO ($p < 0.001$, ***), when comparing MH with PC ($p < 0.001$, ***), when comparing MI with MO ($p < 0.001$, ***), when comparing MI with PC ($p < 0.01$, **), when comparing MO with PC ($p < 0.05$, *), when comparing MO with Vi ($p < 0.001$, ***), and respectively when comparing PC with Vi ($p < 0.05$, *). In the case of the other comparisons between the grapevine cultivars, based on the W+BW values, the differences did not show statistical certainty ($p > 0.05$), table 5.

The variation of the morphological parameters in the grapevine was studied in relation to different varieties, to environmental factors, technological factors, stress factors, or interactions of some categories of factors [20], [12], [9], [24].

Fractal analysis has been promoted in studies of different plant species, for the analysis of leaf geometry, for the characterization of genotypes and for the classification of studied species [2], [3], [21].

In ampelographic studies, fractal analysis was a useful tool for the generation of additional parameters, in the schematic analysis and classification of grapevines [14], [15], [16].

Under the conditions of the present study, the fractal analysis generated different parameters (D1, D2, BW, B+BW, W+BW) that described the geometry of the leaves of seven vine cultivars considered in the study. Applied comparative analysis (ANOVA test, PHC), leading to differentiated results depending on the fractal parameter used. The method used ensured statistically safe results depending on the fractal parameter and the vine cultivars.

Conclusions

In relation to the purpose of the study, parameters resulting from the fractal analysis (D1, D2, BW, B+BW, W+BW) facilitated the comparative analysis of the seven grapevine cultivars considered in the study.

The common method of comparative analysis (ANOVA) led to different results, in relation to the fractal parameter considered in the analysis.

Parameters D1 and B+BW led to statistically safe results in the comparative analysis of the CS cultivar with the other cultivars. Based on the D1 parameter, differences were recorded in safety conditions at the level of $p < 0.05$ (*) in the case of four comparative analyzes (CS with MH, MI, MO and respectively with Vi). Based on the B+BW parameter, differences were recorded in terms of statistical safety at the level of $p < 0.001$ in the case of five comparative analyzes (CS with Ch, MH, MI, MO and Vi), and differences at the level of safety $p < 0.01$, in the case of the comparative analysis CS with PC.

Based on the BW parameter, there were differences in statistical safety conditions in the case of six comparative analysis, one comparative analysis at the level of $p < 0.05$, (MO with PC), three comparative analyses at the level of $p < 0.01$ (CS with Ch, MI with MO, and MO with Vi), and respective two comparisons at $p < 0.001$ level (Ch with MO and MH with MO).

Based on the W+BW parameter, differences in statistical safety were found in the case of 14 comparative analysis, three comparative analyzes at the $p < 0.05$ significance level (Ch with MH, MO with PC, PC with Vi), one comparative analysis at the level of $p < 0.01$ (MI with PC), and respectively ten comparative analysis at $p < 0.001$ level (CS and Ch, CS with MH, CS with MI, CS with PC, CS with Vi, Ch with MO, MH with MO, MH with PC, MI with MO, and MO with Vi).

In the case of D2 parameter, the comparative analysis led to results without statistical certainty.

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