JOURNAL of Horticulture, Forestry and Biotechnology
Volume 28(2), 2024, 10-17
https://jhfb.ro/index.php/jhfb
Print ISSN: 2066-1797
Online ISSN: 3045-1876

Grapevine leaf geometry description by fractal analysis – Case study in Muscat Hamburg

Alin DOBREI [1], Florin SALA [1, 2,*]

[1] University of Life Sciences "King Mihai I" from Timisoara, Faculty of Engineering and Applied Technologies, Department of Horticulture, e-mail: alin1969tmro@yahoo.com
[1] University of Life Sciences "King Mihai I" from Timisoara, Faculty of Agriculture, Department of Soil Science, e-mail: florin_sala@usvt.ro
[2]Agricultural Research and Development Station Lovrin, Lovrin, Romania, e-mail: florin_sala@usvt.ro

* Corresponding author: florin_sala@usvt.ro

Manuscript received: 30 September 2024; revised: 5 October 2024; accepted: 30 October 2024

Abstract
The aim of the study was to analyze vine leaf geometry based on fractal geometry parameters. The biological material was represented by Muscat Hamburg grapevine cultivar. For the study 20 vine leaves were randomly sampled. From the set of sampled leaves, 15 leaves were scanned in a 1:1 ratio. The digital images, in binarized format, were analyzed by the box-counting method. The Anova test confirmed the reliability of the data and the presence of variance in the series of experimental data. The data series of the fractal parameters (D1, D2) presented a normal distribution. The regression analysis led to obtaining equations that described the variation of fractal dimensions D1 (0.5) and D2 (0.2) in relation to FP and the TP:FP ratio (TP – total pixels; FP – foreground pixels). The variation of D1 and D2 in relation to FP was described by linear equations ($p<0.001$; $R^2 = 0.978$ in the case of D1; $R^2 = 0.942$ in the case of D2). The variation of D1 and D2 in relation to TP:FP was described by polynomial equations ($p<0.001$; $R^2 = 0.984$ in the case of D1; $R^2 = 0.953$ in the case of D2). Fractal dimensions D1 and D2 showed close interdependence ($p<0.001$, $R^2 = 0.976$). The fractal dimension D1 (0.5) presented higher values of the regression coefficient in the analysis with FP and TP:FP parameters.

Keywords: box-counting, fractal analysis, fractal dimension, leaf blade, leaf parameters, vine leaves

Introduction

Plant organisms, or segments of plant organisms, rarely fit simple shapes (e.g. lines, squares, circles, cubes) to be described by specific relations of Euclidean geometry [9], and fractal analysis has shown interest as a method alternatives, for such studies [11].

The box counting analysis method was used to analyze vine leaves [11]. Vine leaves have a complex structure, and a special characteristic in relation to theoretical fractals [11]. The author communicated significant fractal dimensions for the grape varieties studied, and considered that the fractal dimensions can be used as a descriptive parameter (invariant to the scale), morphometric, useful in ampelographic studies.

In the ampelographic studies and research, a series of morphological elements of the leaves such as petiole length, surface, angles, number of teeth, etc., were used for the classification of grape varieties [12]. Some studies have suggested the need for additional parameters to capture the geometry of the leaves for ampelographic studies, and in this sense reference was made to fractal analysis [12].

Through the imaging digitization of vine leaves, analysis techniques were developed in the RGB color system to obtain the fractal spectrum and the calculation of a set of different parameters [13]. Based on fractal data, the author succeeded in discrimination at a comparative level with methods based on studies with molecular markers.

Texture is an attribute of an image, which shows the way the pixels that compose the image are organized [3]. Texture analysis requires a complex and sophisticated work process [3]. Backes et al. (2009) [3] used study and analysis methods based on volumetric fractal dimension (volumetric fractal dimension) of some textures, expressed by leaves from different species.

Manual methods in the study of plants (e.g. taxonomic classification) represent complex tasks, with substantial time consumption [4]. The authors considered it important to promote other methods, such as those based on color texture, through the analysis of color channels (RGB), the modeling of leaf texture on each color channel, as well as in the interaction of the three channels [4].

For the description of some plant organisms, or segments of some organisms, or the way of development of some structures of plant organisms (e.g. fern leaf, leaves), a set of mathematical equations was considered necessary to realistically describe these things [10]. To describe the characteristics of the leaves, some studies have determined the fractal dimension (D) for the limb outline and limb venation through fractal analysis [6]. The authors determined the fractal dimension of the images for the edge of the leaves (perimeter) and the images with multiple veins, in order to study the shape of the leaves.

Fractal dimensions in different tree species were determined [5]. The fractal dimensions were checked and confirmed by the box counting method. Later, other methods were proposed, such as the relationship between the fractal dimension of a leaf and the surface density of the respective leaf image [5]. Fractal analysis was used to describe the leaf geometry of five apple cultivars [17]. Based on the fractal dimensions, it was possible to differentiate the five varieties of apple, under conditions of statistical safety. Agapie et al. (2020) [2] used fractal analysis to characterize leaf texture in soybean genotypes. The authors of the study analyzed two soybean genotypes and obtained values of the fractal dimensions that differentiated the two genotypes with statistical certainty ($p<0.001$).

Indices and foliar parameters that express the complexity of the leaf shape in different plant species are of interest to understand and describe the adaptation and resistance of plants in relation to environmental factors, and especially in relation to global changes, such as climate changes [18].

Fractal dimension and topological entropy are considered defining elements of the complexity of leaf shape, which can capture with high sophistication variations in leaf geometry [18]. Different biological structures (complexes) were analyzed and characterized by fractal analysis, by the method based on box counting [19]. The method has advantages, but some limitations of the method were also considered for certain biological structures analyzed, according to the authors.

The present study used fractal analysis to analyze the geometry of vine leaves of the Muscat Hamburg variety.

Material and Method

Grapevine leaves were analyzed to describe the geometry of the leaf blade. Samples of mature leaves were randomly collected from the Muscat Hamburg grape variety. Twenty leaves were collected, of which 15 leaves without defects, were analyzed. The petiole was removed, and only the leaf blade was used.

To obtain the digital images, each leaf (leaf blade) was scanned. The scanning was done in a 1:1 ratio, 200 DPI resolutions. The digital images were analyzed to obtain parameters related to the fractal geometry. The box-counting method was used in fractal analysis [20], [15]. Each image was analyzed in binarized format. An example of a leaf processed for analysis is presented in figure 1. For the fractal analysis, the following parameters were considered: total pixels (TP), foreground pixels (FP), fractal dimension under the conditions of an analysis parameter of 0.50 (D1) and a parameter of 0.20 (D2).

The fractal dimensions (D1, D2) were obtained according to relations (1), (2), (3), under statistically safe conditions. Example of regression line (Ln Count vs Lnε), resulting from the process of fractal analysis, is presented in figure 2, with Slope = 1.85, under conditions of R^2 = 0.998, This confirmed the statistical reliability and the high precision of the fractal analysis in the case of each vine leaf, the Muscat Hamburg variety.

$$D = m\left[\frac{\ln(F)}{\ln \varepsilon}\right] \quad (1)$$

where: D – fractal dimension;
m – slope to regression line, from equation (2);
F – number of new part;
ε – scale applied to an object.

$$m = (n\sum SC - \sum S \sum C)/(n\sum S^2 - (\sum S)^2) \quad (2)$$

JOURNAL of Horticulture, Forestry and Biotechnology
Volume 28(2), 2024, 10-17
https://jhfb.ro/index.php/jhfb
Print ISSN: 2066-1797
Online ISSN: 3045-1876

where: m – slope of the regression line;
S – log of scale or size;
C – log of count;
n – number of size;

$$Mean\,D = \sum(D)/GRIDS \qquad (3)$$

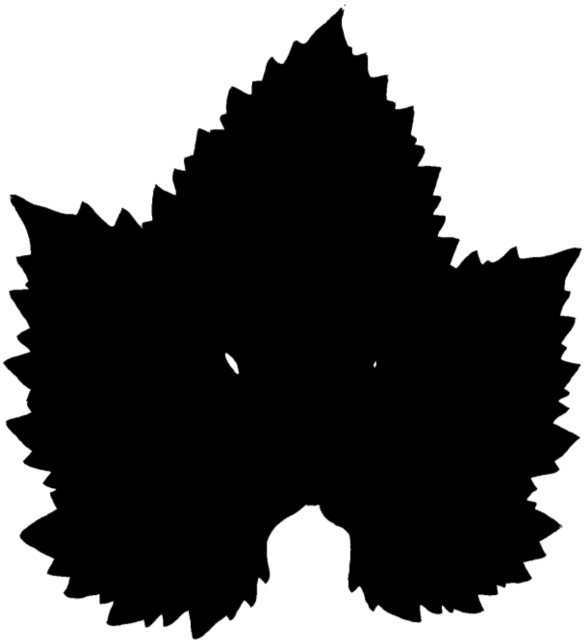

Figure 1. Grapevine leaf, Muscat Hamburg cultivar

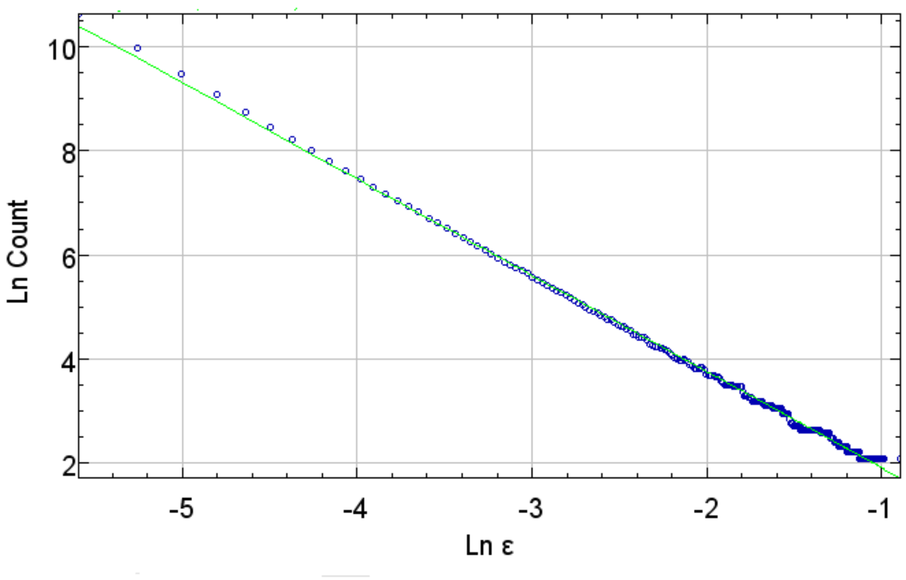

Figure 2. Regression line resulting from fractal analysis, vine leaves, Muscat Hamburg cultivar

The results of the study were analyzed to evaluate the safety of the data and the presence of variance (ANOVA Test). Regression analysis was done to analyze the variation of D1 and D2 data in relation to PF and the TP:FP ratio. Appropriate applications were used for calculations and the generation of graphic

JOURNAL of Horticulture, Forestry and Biotechnology
Volume 28(2), 2024, 10-17
https://jhfb.ro/index.php/jhfb
Print ISSN: 2066-1797
Online ISSN: 3045-1876

representations [7].

Results and Discussion

The analysis of the images, resulting from the scanning of grape vine leaves, the Muscat Hamburg variety, led to the data presented in table 1. The TP parameter (total pixels) presented the same value in all cases.

The FP parameter presented different values. Based on the two parameters, the TP/FP ratio was calculated, which recorded values between TP/FP = 2.284 and TP/FP = 6.848.

The D1 and D2 values presented specific, in accordance with the study conditions. The ANOVA test confirmed the safety of the data ($p<0.001$; Alpha = 0.001), table 2. Data series D1 and D2 presented a normal distribution, figure 3.

Table 1. Fractal analysis parameter values, FP, D1 and D2, vine leaves, Muscat Hamburg cultivar

Leaf sample	Total Pixels	Foreground Pixels	TP/FP	D1	D2
F1	3059899	1180572	2.592	1.886	1.840
F2		471948	6.484	1.800	1.765
F3		1215995	2.516	1.888	1.836
F4		1023317	2.990	1.870	1.835
F5		1316948	2.323	1.894	1.846
F6		1311294	2.333	1.901	1.849
F7		1254868	2.438	1.897	1.848
F8		1007874	3.036	1.867	1.818
F9		1157581	2.643	1.879	1.835
F10		1050718	2.912	1.867	1.819
F11		951084	3.217	1.862	1.818
F12		1183332	2.586	1.885	1.835
F13		1172328	2.610	1.891	1.842
F14		822832	3.719	1.836	1.792
F15		1339954	2.284	1.900	1.848

Table 2. ANOVA Test

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.2042E+13	2	6.02E+12	351.795	5.83E-27	8.179405
Within Groups	7.1885E+11	42	1.71E+10			
Total	1.2761E+13	44				

Regression analysis was used to evaluate the variation of parameters D1 and D2 in relation to FP. The variation of D1 according to FP was described by the linear equation (4), under conditions of $R^2 = 0.978$, $p<0.001$, F = 577.97. The graphic distribution of D1 values in relation to FP is presented in figure 4.

$$D1 = 1.182E-07 \cdot x + 1.745 \quad (4)$$

where: *x* – FP

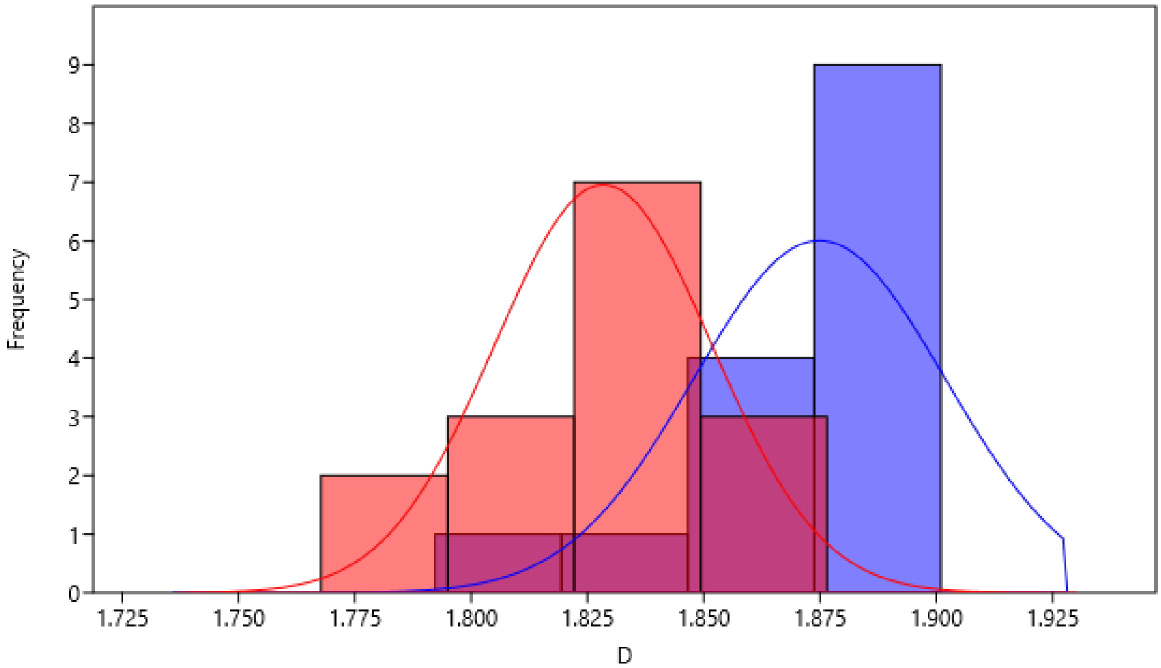

Figure 3. Histogram of distribution of D1 and D2 values, vine leaf, Muscat Hamburg cultivar

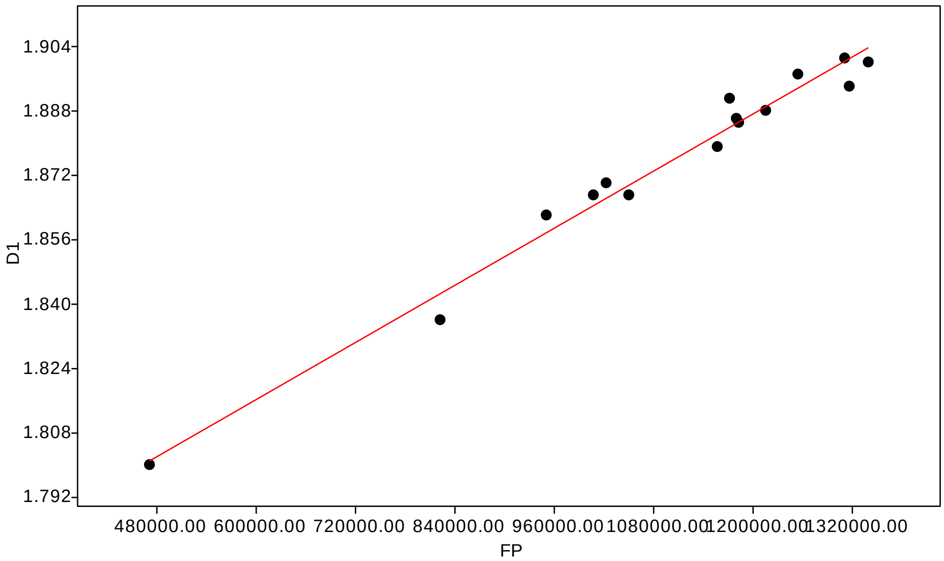

Figure 4. Graphic distribution of D1 values in relation to FP, vine leaves, Muscat Hamburg variety

The variation of D2 according to FP was described by the linear equation (5), under conditions of $R^2 = 0.942$, $p<0.001$, $F = 210.29$. The graphic distribution of D2 values in relation to FP is presented in figure 5.

$$D2 = 1.002E{-}07 \cdot x + 1.718 \quad (5)$$

where: x – FP

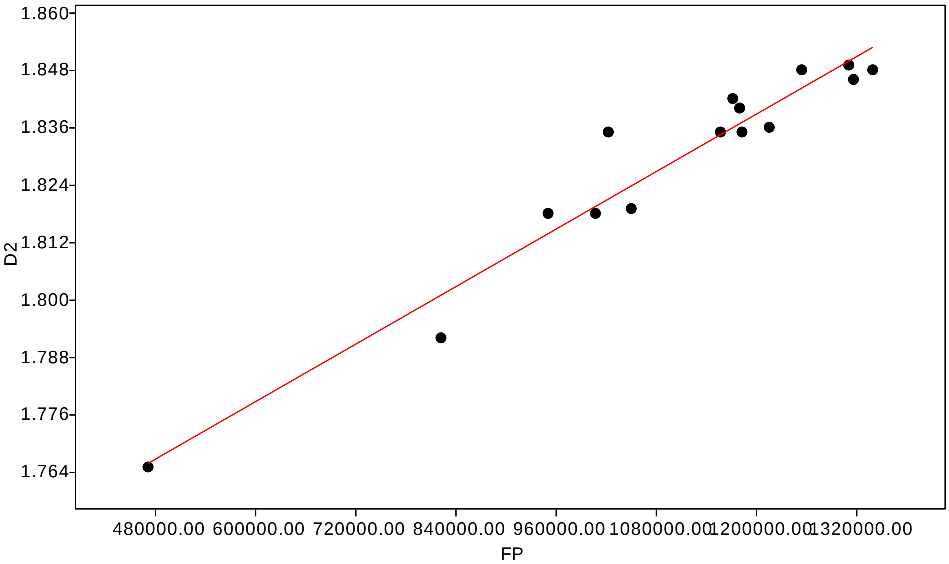

Figure 4. The graphic distribution of D1 values in relation to FP, vine leaves, Muscat Hamburg cultivar

The calculated TP: FP ratio led to values between TP: FP = 2.284 and TP: FP = 6.484. In relation to the calculated TP: FP ratio values, the fractal dimensions D1 and D2 presented specific variations. The variation of D1 depending on the TP: FP values was described by the polynomial equation (6), under conditions of R^2 = 0.984, p<0.001, F = 380.03. The D2 variation depending on the TP: FP values was described by the polynomial equation (7), under conditions of R^2 = 0.953, p<0.001, F = 121.

$$\mathrm{D1} = 0.00675 \cdot x^2 - 0.08334 \cdot x + 2.056 \qquad (6)$$

$$\mathrm{D2} = 0.005716 \cdot x^2 - 0.07063 \cdot x + 1.982 \qquad (7)$$

Where: x – TP/FP values

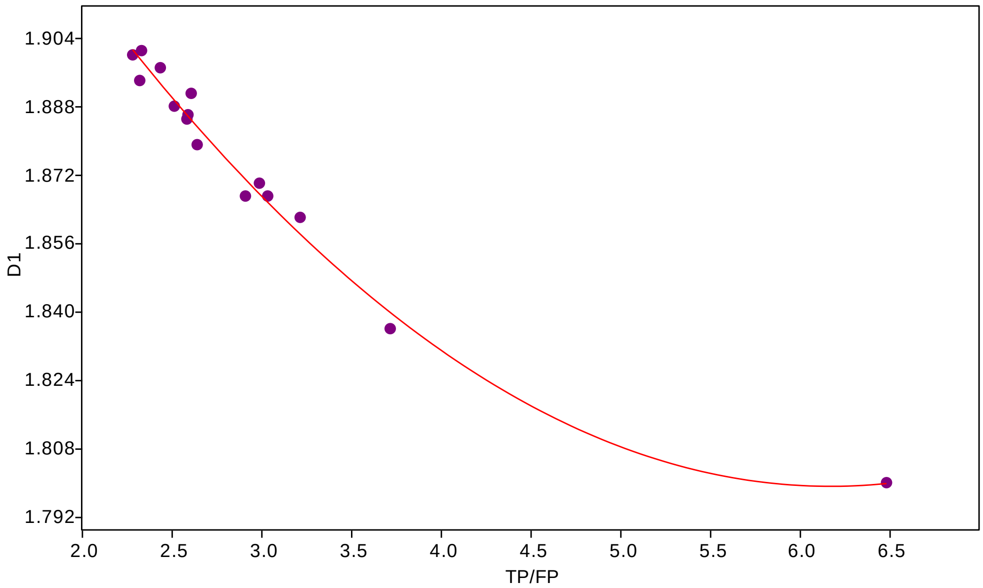

Figure 5. Distribution of D1 values in relation to TP: FP ratio values, vine leaves, Muscat Hamburg cultivar

JOURNAL of Horticulture, Forestry and Biotechnology
Volume 28(2), 2024, 10-17
https://jhfb.ro/index.php/jhfb
Print ISSN: 2066-1797
Online ISSN: 3045-1876

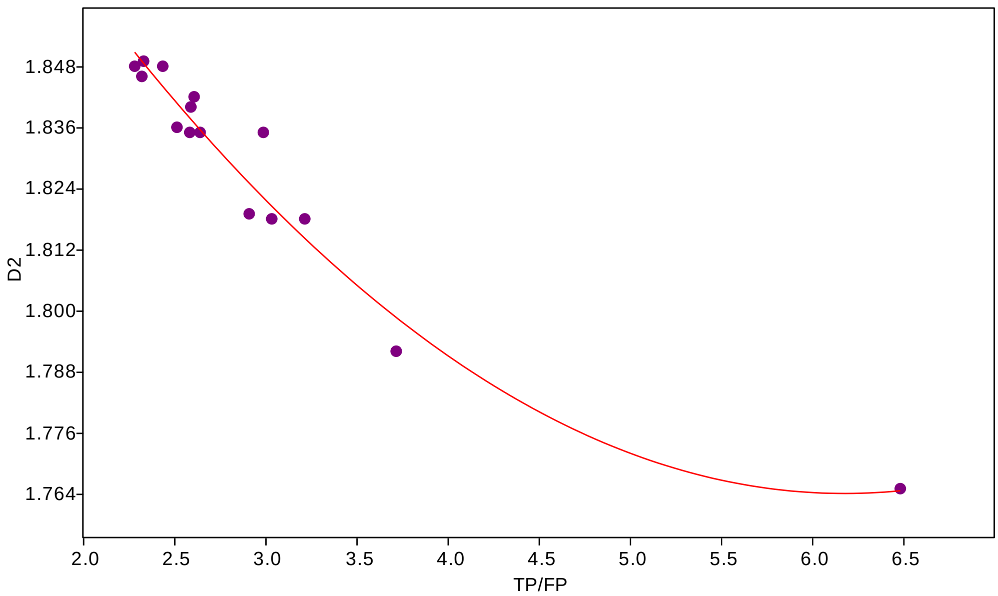

Figure 6. The distribution of D2 values in relation to the values of the TP: FP ratio, vine leaves, Muscat Hamburg cultivar

The interdependence relationship between D2 and D1 was described by equation (8), under conditions of $R^2 = 0.976$, $p<0.001$, $F = 519.55$.

$$D2 = 0.8528 \cdot D1 + 0.2296 \quad (8)$$

Vine vegetation parameters vary in relation to the genotype, environmental conditions, crop technology, and the interactions between the respective factors [1]. Characteristics of the genotype, the environmental conditions, the state of supply with mineral elements, the water regime, the technological system of exploitation, influence the state of vegetation, parameters and foliar indices [16], [8], [14]. The leaves express the typicality of the genotype, but register certain variations in relation to the environmental conditions.

The FP parameter showed a fairly wide variation, depending on the size of the shape of the vine leaves in the digital images (1:1 ratio). The TP/FP ratio also showed a variation strongly dependent on the FP values.

The values of the fractal dimensions showed a reduced variation, which shows that the fractal dimension represents a stable parameter for describing the geometry of the leaves' shape in the vine.

Similar results regarding the constancy of the fractal dimension in the description of the leaf geometry were reported by previous studies [12], [19].

The variation of fractal dimensions (D1, D2) in relation to FP was described by linear equations, under statistical safety conditions ($p<0.001$), with higher safety in the case of D1 ($R^2 = 0.978$), compared to D2 ($R^2 = 0.942$).

The variation of D1 and D2 in relation to the TP/FP ratio was described by polynomial equations ($p<0.001$). And in this case, the D1 variation in relation to TP/FP showed higher reliability ($R^2 = 0.984$), compared to D2 ($R^2 = 0.953$).

This suggests that D1 describes more accurately the geometry of vine leaves compared to D2, under the conditions of the present study.

Conclusions

Fractal analysis, the box-counting method, facilitated the obtaining of some parameters of the geometry of the leaves of the vine, the Muscat Hambug cultivar, for the description of the leaf limb.

The FP parameter showed variable values, in relation to the geometry of the leaf limb. The TP:FP ratio (constant TP, variable FP) recorded values between 2.284 and 6.484, depending on the size of the FP, associated with the geometry of the leaf blade.

The fractal dimensions, D1 and D2, faithfully expressed the geometry of the vine leaves, under statistical safety conditions, $R^2 = 0.998$. Data series D1 and D2 presented normal distribution. The variation of fractal dimensions (D1, D2) in relation to FP was described by linear equations, under statistical safety conditions, $p<0.001$. The fractal dimensions D1 and D2 showed a very strong interdependence ($R^2 = 0.976$). The variation of D2 in relation to D1 was described by a linear equation, under statistical safety conditions ($p<0.001$).

Acknowledgements

Publishing of this journal is supported by the Institute for Plant Biotechnology of the University of Life Sciences "King Mihai I" from Timisoara.

References

[1] Abubakar, M.A., Chanzy, A., Fabrice, F., Courault, D. (2023), *Characterisation of Grapevine Canopy Leaf Area and Inter-Row Management Using Sentinel-2 Time Series*. OENO One, 57(4): 1-13.
[2] Agapie, A.L., Horablaga, M.N., Gorinoiu, G., Sala, F. (2020), *Fractal analysis for soybean leaves characterization*. AIP Conference Proceedings, 2293: 350003.
[3] Backes, A.R., Casanova, D., Bruno, O.M. (2009), *Plant leaf identification based on volumetric fractal dimension*. International Journal of Pattern Recognition and Artificial Intelligence, 23(6): 1145-1160.
[4] Backes, A.R., Bruno, O.M. (2010), *Plant leaf identification using color and multi-scale fractal dimension*. In: Elmoataz A., Lezoray O., Nouboud F., Mammass D., Meunier J. (Eds) *Image and signal processing*. ICISP 2010. Lecture Notes in Computer Science, 6134: 463-470.
[5] Bayirli, M., Selvi, S., Cakilcioglu, U. (2014), *Determining different plant leaves' fractal dimensions: a new approach to taxonomical study of plants*. Bangladesh Journal of Botany, 43(3): 267-275.
[6] Du, J., Zhai, C.-M., Wang, Q.-P. (2013), *Recognition of plant leaf image based on fractal dimension features*. Neurocomputing, 116: 150-156.
[7] Hammer, Ø., Harper, D.A.T., Ryan, P.D. (2001), PAST: *Paleontological Statistics software package for education and data analysis*. Palaeontologia Electronica, 2001, 4(1): 1-9.
[8] Harris, Z.N., Pratt, J.E., Bhakta, N., Frawley, E., Klein, L.L., Kwasniewski, M.T., Migicovsky, Z., Miller, A.J. (2022), *Temporal and environmental factors interact with rootstock genotype to shape leaf elemental composition in grafted grapevines*. Plant Direct, 6(8): e440.
[9] Hartvigsen, G. (2000), *The analysis of leaf shape using fractal geometry*. American Biology Teacher, 62: 664-669.
[10] Lev-Yadun, S. (2012), *Fern leaves and cauliflower curds are not fractals*. Plant Signaling & Behavior, 7(5): 533-534.
[11] Mancuso S. (1999), *Fractal geometry-based image analysis of grapevine leaves using the box counting algorithm*. Vitis, 38(3): 97-100.
[12] Mancuso, S. (2001), *The fractal dimension of grapevine leaves as a tool for ampelographic research*. HarFA - Harmonic and Fractal Image Analysis, 6-8.
[13] Mancuso, S. (2002), *Discrimination of grapevine (Vitis vinifera L.) leaf shape by fractal spectrum*. Vitis, 41(3): 137142.
[14] Matese, A., Di Gennaro, S.F., Orlandi, G., Gatti, M., Poni, S. (2022), *Assessing grapevine biophysical parameters from unmanned aerial vehicles hyperspectral imagery*. Frontiers in Plant Sciences, 13: 898722.
[15] Rasband, W.S. (1997), *Image* J. U. S. National Institutes of Health, Bethesda, Maryland, USA, pp. 1997-2014.
[16] Sala, F., Blidariu, C. (2012), *Macro-and micronutrient content in grapevine cordons under the influence of organic and mineral fertilization*. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Horticulture. 69(1): 317-324.
[17] Sala, F., Iordănescu, O., Dobrei, A. (2017), *Fractal analysis as a tool for pomology studies: case study in apple*. AgroLife Scientific Journal, 6(1): 223-233.
[18] Vishnu, M., Jaishanker, R. (2023), *Fractal-Thermodynamic system analogy and complexity of plant leaves*. Environmental Research Communications, 5: 055013.
[19] Vishnu, M., Sajeev, C.R., Jaishanker, R. (2023), *Determining the limits of traditional box-counting fractal analysis in leaf complexity studies*. Flora, 304: 152300.
[20] Voss, R. (1985), *Random fractal forgeries*. In: Earnshaw R. (Ed.) Fundamental algorithms for computer graphics, Sringer Verlag, Berlin, pp. 805-835.