FRACTAL CHARACTERIZATION OF LEAF GEOMETRY IN *Populus alba* L.

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Abstract. *The study used fractal analysis to evaluate and describe the geometry of the leaves at the Populus alba L. specie. The leaf samples were taken randomly, from mature trees, from the Cenad Forest Protected Area, Timis County, Romania. The leaves were scanned in a 1:1 ratio, and binarized images of the leaves were used for fractal analysis of leaf geometry. The box-counting method was used for the fractal analysis in order to obtain the values of the fractal dimensions (D). Foreground pixels (FP), correlation coefficient R^2 for D, and standard error (SE) were recorded. The values of the parameters of the leaves L (leaf length), w (leaf width), Per (perimeter), and SLA (scanned leaf area) were determined. The ANOVA test (Alpha = 0.001) confirmed the statistical safety of the data and the presence of variance in the data set (p <0.001, F> Fcrit). The coefficient of variation (CV) indicated the values: CV_L = 14.910 for the leaf length parameter (L), CV_w = 19.531 for the leaf width parameter (w), CV_{Per} = 16.865 for the leaf perimeter (Per), CV_{SLA} = 33.594 for the scanned leaf area (SLA), CV_{FP} = 33.151 for foreground pixels (FP), and respectively CV_D = 2.838 for fractal dimension (D). From the comparative analysis of CV values, it was found that the smallest variation was recorded in the case of fractal dimension (D), and the largest in the case of scanned leaf area (SLA). This suggests that the fractal dimension (D) is the most stable parameter in the characterization of leaf geometry in the species Populus alba L. Diversity profile indicated a similar distribution of the studied parameters. In relation to the dimensional parameters of the leaves, the variation of the fractal dimensions (D) had variable interdependence relations, in conditions of R^2 = 0.878 in relation to FP, R^2 = 0.908 in relation to Per, R^2 = 0.909 in relation to SLA, R^2 = 0.799 in relation to L and, respectively, R^2 = 0.698 in relation to w. Polynomial equations, of degree 2, described the variation of the fractal dimensions D in relation to FP, Per and SLA, in statistic safety conditions, p <0.001.*

Keywords*: box-counting, diversity profile, fractal analysis, leaf geometry, Populus alba*

INTRODUCTION

Imaging analysis and fractal analysis are increasingly used in the study of phenomena, processes, realities, as a result of the facilities they offer (MESHCHERYAKOVA and LARIONOVA, 2017; ZAHEDI and ZEIL, 2018; PATUANO and TARA, 2020).

Fractal analysis is a method of investigation with applicability in different fields and which ensures an objective evaluation of the analyzed subjects (GLENNY et al., 1991; GANTI and BHUSHAN, 1995; GONZATO et al., 1998; MAKLETSOV et al., 2020; SALA et al. al., 2020).

In the plant field, fractal analysis has found applicability in the study, characterization and identification of different plant species based on leaf geometry (BRUNO et al., 2008; BACKES et al., 2009; DU et al., 2013, MUSARELLA et al. , 2018), leaf midrib cros-sections (DA SILVA et al., 2015), in plant taxonomy studies etc. (BAYIRLI et al., 2014).

In a study of five apple varieties, fractal analysis was used to characterize leaf geometry and classify genotypes (SALA et al., 2017).

Fractal analysis facilitated the study of the wheat root system in relation to CO_2 concentration (WANG et al., 1998), in relation to heavy metals (LI et al., 2019). Also in wheat crop, fractal analysis was used to analyze the variation of the geometry of the shape of the wheat ear in relation to N fertilization (SALA and RUJESCU, 2017). A recent study reported the results of the evaluation and classification of 10 wheat varieties by fractal analysis of crop geometry in three different stages of vegetation (RUJESCU et al., 2020).

The rhytidome geometry at *Fraxinus angustifolia* Vahl. was studied by fractal analysis, in relation to the images capture distance (NICOLIN et al., 2019), and SALA and BOLDEA (2014) found a model for estimating the age at plum trees, based on the fractal dimensions (D) of the tree bark geometry.

The present study used fractal analysis to describe and characterize the geometry of leaves at the species *Populus alba* L.

MATERIAL AND METHODS

The study used fractal analysis to characterize leaf geometry in *Populus alba* L. specie.

Poplar leaves, taken randomly from the crown of trees, *Populus alba* L. specie (Cenad Forest Protected Area, Timiș County, Romania), were used for analysis.

The leaves were scanned in a 1:1 size ratio. The images were analyzed to evaluate the fractal geometry of the leaves. Binarized images were used, fig. 1.

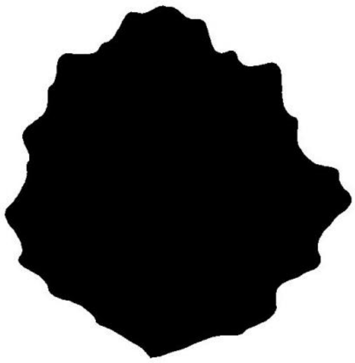

Figure 1. Binarized image, *Populus alba* L. leaf

The box-counting analysis method (Voss, 1985) was used to obtain the fractal dimensions D.

In addition to the fractal analysis, the values of the leaf parameters were recorded (RASBAND, 1997), such as, L (leaf length), w (leaf width), SLA (scanned leaf area), Per (leaf perimeter). The values of foreground pixels (FP), fractal dimensions (D), correlation coefficient for D (R^2), and standard error (SE) were recorded from the fractal analysis.

The ANOVA test was used for the overall analysis of the data set. Experimental data, in terms of the interdependence relationships between foliar parameters and fractal dimension (D), were analyzed by correlation, and regression analysis (HAMMER et al., 2001). The coefficients R^2, r, parameters p, F-test were used to express the statistical certainty of the results.

RESULTS AND DISCUSSIONS

From the analysis of the leaf samples, was found the variation of the leaf length parameter (L) in the range L = 4.6-7.9 ± 0.17, the leaf width parameter (w) in the range w = 3.8-7.8 ± 0.21, the leaf perimeter Per = 14.706-26.30 ± 0.67, and scanned leaf area SLA =

11.093-36.315±1.49. Foreground pixels (FP) varied in relation to leaf size, in the range FP = 71118-235876 ± 9606.317. The fractal dimensions, obtained by the box-counting method, had values in the range D = 1.588-1.771 ± 0.009, in conditions of statistical safety of the fractal analysis, according to R^2 for D and standard error (SE), R^2 = 0.096, SE = 0.080. The graphic distribution in the form of a box plot is presented in figure 2.

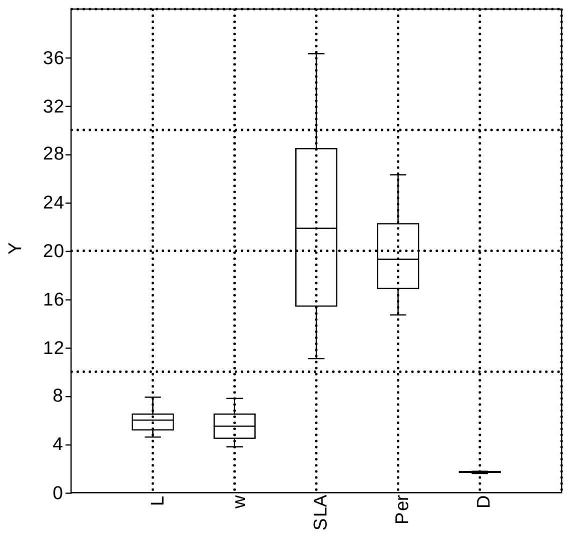

Figure 2. Graphic distribution of values of foliar parameters and fractal dimensions in the case study, *Populus alba* L.

The ANOVA single factor test (Alpha = 0.001) highlighted the safety of the experimental data and the presence of variance in the data set, under the conditions of F = 227.4439, Fcrit =4.3617, p <0.001.

From the analysis of the data set, under the aspect of the coefficient of variation (CV), differentiated values of this index were obtained; CV_L=14.910 for leaf leaf parameter (L), CV_w=19.531 for leaf width parameter (w), CV_{Per}=16.865 for leaf perimeter (Per), CV_{SLA}=33.594 for scanned leaf area (SLA), CV_{FP}=33.151 for foreground pixels (FP), respectively CV_D =2.838 for the fractal dimension (D). From the analysis of CV values, it was found that the smallest variation was recorded in the case of fractal dimensions (D), and the largest in the case of SLA. This suggests that the fractal dimensions (D) is the most stable parameter in the characterization of leaf geometry in the species *Populus alba* L.

The graphical analysis of the variability of the parameters and fractal dimensions of the leaves at *Populus alba* L., similarly expressed the amplitude of variation, in the form of the diversity profile, presented in figure 3.

The variation of D values, depending on foreground pixels (FP) was described by equation (1), under conditions of R^2=0.878, F=79.267, p <0.001, and the graphical distribution is presented in figure 4.

$$\mathrm{D} = -6.136E-12x^2 + 2.746E-06x + 1.447 \tag{1}$$

where x= FP (foreground pixels)

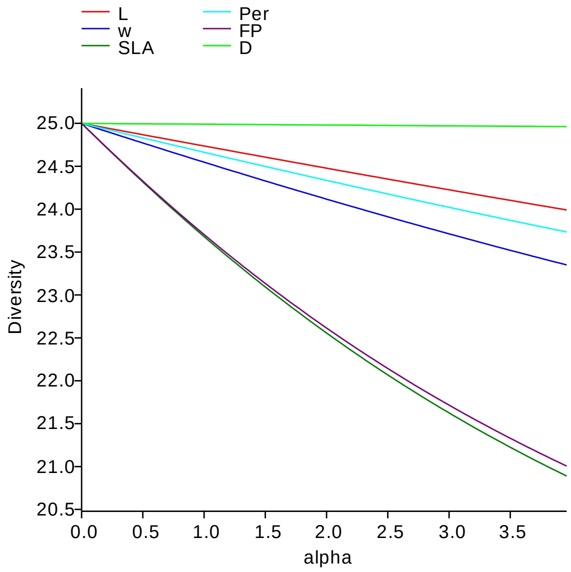

Figure 3. Diversity profile, for foliar parameters and fractal dimensions, *Populus alba* L.

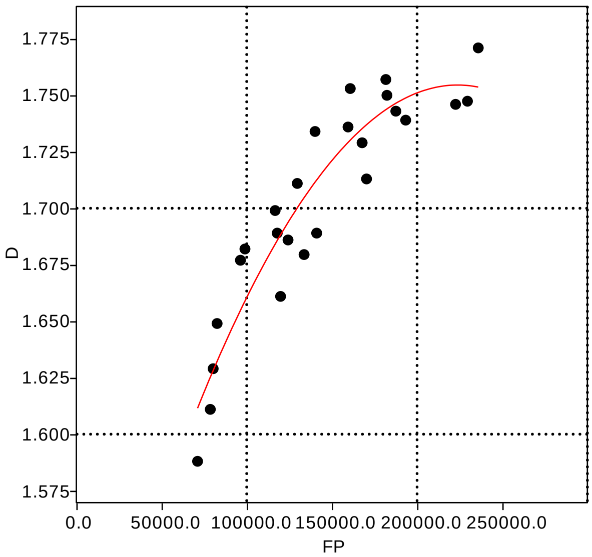

Figure 4. Graphical distribution of D values according to FP values (foreground pixels), *Populus alba* L.

The variation of D values depending on the perimeter of the leaves (Per) was described by equation (2), in conditions of R^2 =0.908, F =109.36, p <0.001, and the graphical distribution is presented in figure 5.

$$D = -0.001411\,x^2 + 0.07014\,x + 0.8818 \quad (2)$$

where: x – Per (perimeter of the leaf)

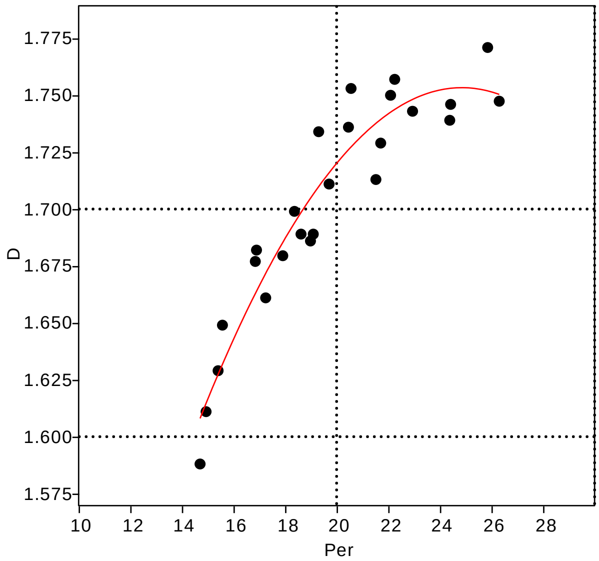

Figure 5. Graphic distribution of D values according to leaf perimeter values (Per), *Populus alba* L.

The variation of D values depending on the scanned leaf area (SLA) was described by equation (3), under conditions of R^2 =0.909, F =109.49, p<0.001, and the graphical distribution is presented in figure 6.

$$D = -0.0002837\,x^2 + 0.0191\,x + 1.433 \quad (3)$$

where: x – SLA (scanned leaf area)

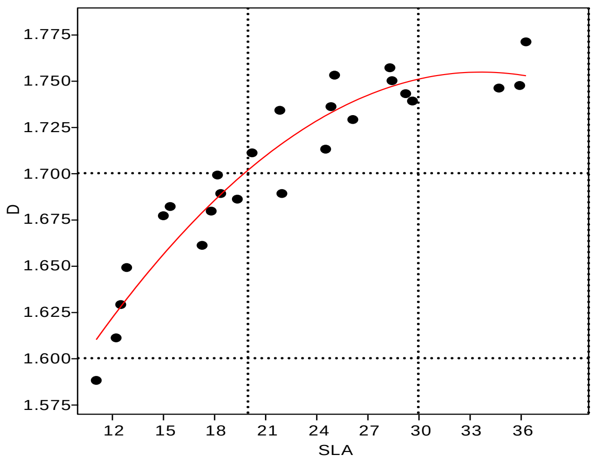

Figure 6. Graphic distribution of D values according to SLA values, *Populus alba* L.

From the analysis of the regression coefficients R^2, of the equations (1), (2) and (3), it was found that the values of the fractal dimensions D had a closer correlation with the leaf perimeter (Per), followed by the SLA and FP. This shows that the perimeter (Per), as an element of leaf geometry, had a much higher importance in defining the values of fractal dimensions (D) compared to the other parameters studied (FP and SLA).

The parameter L (leaf length) and the parameter w (leaf width) had a moderate importance in defining the fractal dimension (D), according to R^2 =0.799 in the case of L and respectively R^2 =0.698 in the case of w.

Multiple regression analysis, which simultaneously addressed the three parameters studied (FP, SLA and Per) in defining fractal dimension D, led to the relationship (4).

$$D = -2.5E-06FP - 0.04514SLA + 0.15441Per \qquad (4)$$

From the analysis of the values of the coefficients of equation (4), resulted the weight of the three parameters studied, as elements of the geometry of the leaves at *Populus alba* L. when defining the fractal dimension (D), in descending order being Per> SLA> FP.

Studies of plant leaves by non-destructive imaging methods have been frequently used for the purpose of leaf surface analysis (SALA et al., 2015; DRIENOVSKY et al., 2017a,b). CÂNDEA-CRĂCIUN et al., (2018) communicated the results obtained by imaging methods regarding the leaf area and the relationship with foliar parameters to four energy poplar clones.

Similar results were reported on the use of fractal analysis to describe leaf geometry in *Alnus glutinosa* (L.) Gaertn., where high correlations were recorded between D and SLA (r = 0.912) and D with Per (r = 0.887), and lower values were found between D and L, respectively D and w (SALA et al., 2020), or at the leaves of five apple cultivars (SALA et al., 2017).

The results communicated in the present study, are in concordance with the scientific literature in the field, which was consulted and was the basis for documenting the present research.

CONCLUSIONS

The fractal analysis, by the box-counting method, facilitated the description of the leaf geometry in the species *Populus alba* L. based on the fractal dimensions D.

Between the fractal dimensions (D) and the dimensional parameters of the leaves, interdependence relations were identified, described by polynomial equations of degree 2 in static safety conditions, p <0.001.

Compared with foliar parameters L, w, Per, SLA, the fractal dimensions D showed high stability in characterizing the geometry of the analyzed leaves at the species *Populus alba* L.

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