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COMPARATIVE ANALYSIS OF SOME TREE SPECIES BASED ON THE RHYTIDOM FRACTAL GEOMETRY

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ABSTRACT

In urban ecosystems, green spaces have high importance and multiple functionality under ecological, social, economic, and cultural aspects. Fractal analysis was used in this study to evaluate the rhytidome geometry of 21 tree species in urban environment, public domain, in the city of Timisoara. Tree samples from the following species were studied: Catalpa bignonioides Walter (T1), Albizia julibrissin Durazz (T2), Carpinus betulus L. (T3), Ailanthus altissima (Mill.) Swingle (T4), Betula alba L. (T5), Pinus nigra J.F. Arnold (T6), Populus alba L. (T7), Platanus orientalis L. (T8), Corylus colurna L. (T9), Robinia pseudoacacia L. (T10), Elaeagnus angustifolia L. (T11), Liriodendron tulipifera L. (T12), Ginkgo biloba L. (T13), Salix babylonica L. (T14), Quercus robur L. (T15), Castanea sativa Mill. (T16), Prunus cerasifera Nigra Ehrt (T17), Morus nigra L. (T18), Tilia cordata Mill. (T19), Jugland regia L. (T20), Paulownia tomentosa (Thunb.) Steud (T21). The values of fractal dimension (D) varied between D = 1.7962±0.0040 in the case of T7, and D = 1.9001±0.0034 in the case of T2. The values of fractal dimensions showed low variability in all cases, CV = 0.0995 in the case of T3 and CV = 0.9618 in the case of T10. Mathematical and statistical analysis tests confirmed the difference between the mean and median values of fractal dimensions, related to the considered tree species. Dunn's post hoc test showed the level of statistical confidence in the comparative evaluation of tree species, and cluster analysis showed variable levels of similarity between species, based on the values of fractal dimensions (D).

KEY WORDS: *bark geometry, complexity, diversity index, fractal analysis, tree species, urban ecology*

INTRODUCTION

Fractal dimension (D) has been considered an invariant parameter, governing elements of geometry in the natural world, which captures finer details of the line (straight line) at a smaller scale (smaller units of measurement) (Zeide, 1991).

The complex shape of the plant leaves was evaluated through fractal analysis, which ensured the identification of plant species considered in the study, based on fractal dimension (Bruno *et al*., 2008; Vishnu *et al*., 2023). Studies of plant species identification and classification were conducted based on the fractal dimension of leaf geometry using new algorithms that ensured high accuracy (Jobin *et al*., 2012). The root system of plants has been studied through fractal analysis to quantify the relationship of plants with the soil and biological and physiological advantages in plant growth and development (Hai *et al*., 2023).

Fractal geometry has been used to estimate tree and shrub values through analysis of terrestrial laser images (Guzmán *et al*., 2020). Morphological and physiological traits, specific to trees, were quantified through fractal geometry as an expression of the mode of adaptation in relation to urban environmental conditions (Arseniou and MacFarlane, 2021).

The geometry of the tree crown shape, through fractal dimension (D), was considered a suitable indicator to describe certain tree characteristics, crown class, tolerance to environmental factors, association with the site, site quality (Zeide, 1991; Pluciński *et al*., 2008; Ianovici *et al*., 2015). The estimation of the fractal dimension of the crown shape of some tree species has been analyzed based on digital images, and has been promoted as a method of interest for classifying tree structure (Zhang *et al*., 2007). The tree branching system was studied based on fractal properties in a two-dimensional system, through Fourier-type mathematical analysis (Grigoriev *et al*., 2022).

The relationship of some tree species with environmental factors and tree health was evaluated through fractal analysis of tree crown images (Murray *et al*., 2018). The authors of the study appreciated the potential of the fractal method, the correspondence of this approach with conventional methods, but also considered the need for additional adjustments to increase the precision of interspecific thresholds (Murray *et al*., 2018).

In studies of tree species classification, methods that used specific vectors based on fractal geometry have been developed and promoted (Hui *et al*., 2023). Fractal analysis has been used to characterize the ecotones of vascular plants and to characterize their spatial distribution patterns under specific environmental conditions (Ncube *et al*., 2025).

This study comparatively analyzed 21 tree species from the urban ecosystem, based on the fractal dimension of rhytidome geometry.

MATERIALS AND METHODS

In relation to the purpose of the study, images of stem rhytidome were captured in a series of tree species, from the public domain, Timisoara city, Timis County, Romania.

The biological material was represented by 21 tree species: *Catalpa bignonioides* Walter (T1), *Albizia julibrissin* Durazz (T2), *Carpinus betulus* L. (T3), *Ailanthus altissima* (Mill.) Swingle (T4), *Betula alba* L. (T5), *Pinus nigra* J.F. Arnold (T6), *Populus alba* L. (T7), *Platanus orientalis* L. (T8), *Corylus colurna* L. (T9), *Robinia pseudoacacia* L. (T10), *Elaeagnus angustifolia* L. (T11), *Liriodendron tulipifera* L. (T12), *Ginkgo biloba* L. (T13), *Salix babylonica* L. (T14), *Quercus robur* L. (T15), *Castanea sativa* Mill. (T16), *Prunus cerasifera Nigra* Ehrt (T17), *Morus nigra* L. (T18), *Tilia cordata* Mill. (T19), *Jugland regia* L. (T20), *Paulownia tomentosa* (Thunb.) Steud (T21). T1 to T21 represent the species codes used in this article, in various mathematical and statistical analyses, and for tabular and graphical presentation.

The digital images were captured in August 2022, with a mobile device, (smartphone, 2988 x 5312 pixels, 72 dpi resolution, bit depth 24, sRGB). The trunk area considered for digital image capture was at a height of 1.3 m. Ten images were captured for each species, under similar conditions. The digital images were processed for fractal analysis. From each image, the central area was considered, from which a crop was made with dimensions of 2305 × 2305 pixels. Fractal analysis was performed using the box counting method, on binarized images (Voss, 1985; Rasband, 1997), figure 1. The fractal dimension D was obtained according to equation (1).

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

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

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

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

The recorded data were analyzed for general statistical characterization (Descriptive Statistical Analysis), to evaluate the presence of variance and data safety (ANOVA Test), for the safety of the data series distribution (Mann-Kendall trend test), for the differentiation of tree species (Comparative analysis), and for the evaluation of the similarity level (Cluster Analysis). In relation to the tests considered, the PAST software v. 4.17 was used (Hammer *et al*., 2001).

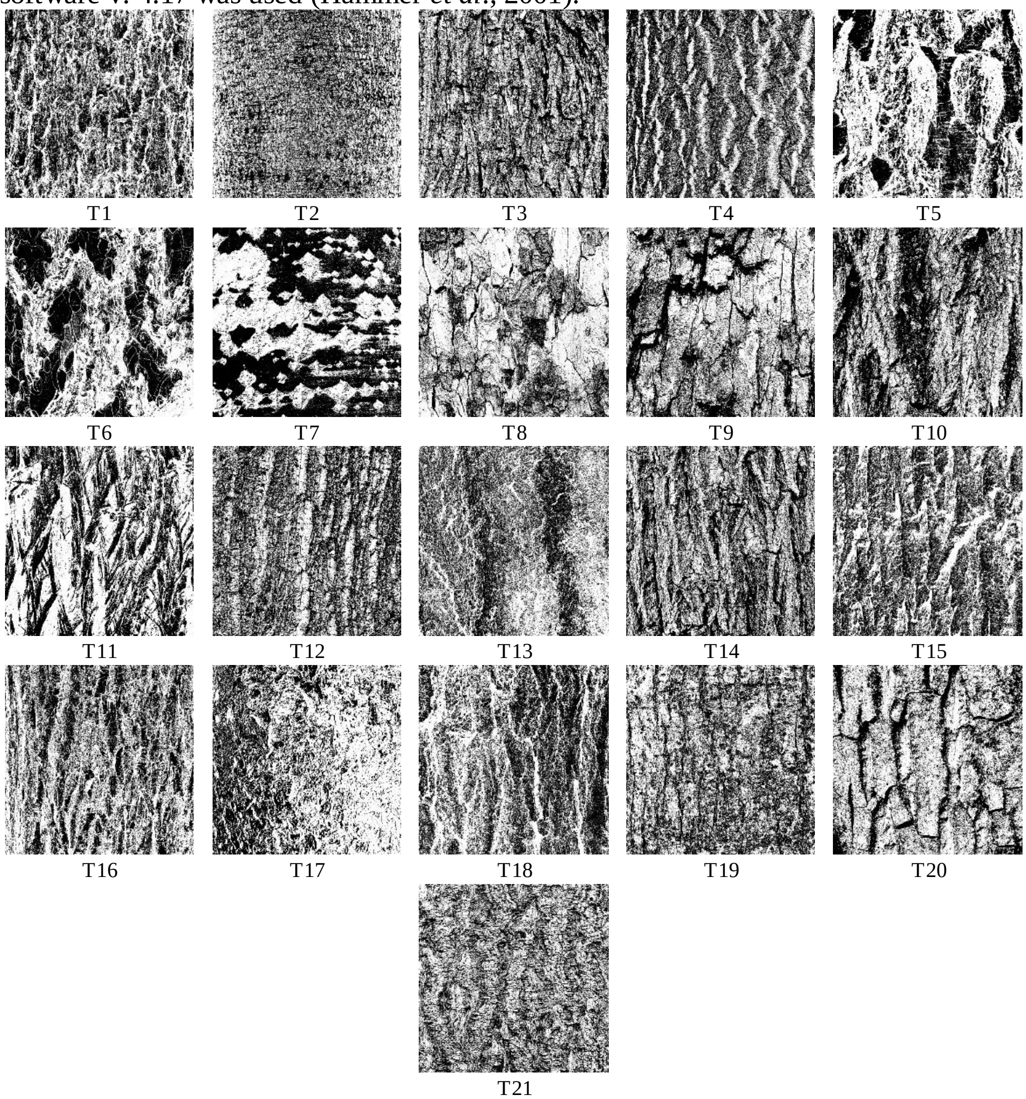

FIG. 1. Binarized images of rhytidome in the studied arboreal species (original images, by Florin Sala)

RESULTS AND DISCUSSIONS

From the analysis of digital images, data series emerged that expressed the fractal geometry of the stem rhytidome in 21 tree species. Descriptive statistical analysis of the data series led to the values in table 1. The graphic representation of the fractal dimension (D) on the studied tree species (trials, T1 to T21) is presented in figure 2.

TABLE 1. Results of descriptive statistical analysis

Statistical parameters	Trials																				
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Min	1.8867	1.8863	1.8890	1.8646	1.8210	1.8214	1.7838	1.8520	1.8566	1.8331	1.8448	1.8920	1.8828	1.8767	1.8816	1.8934	1.8761	1.8718	1.8571	1.8704	1.8908
Max	1.8962	1.9111	1.8943	1.9064	1.8552	1.8663	1.8226	1.8807	1.8820	1.8896	1.8766	1.9039	1.9074	1.8915	1.8987	1.9038	1.9012	1.8979	1.8999	1.8888	1.8986
Sum	18.8981	19.0013	18.9198	18.9241	18.3976	18.4979	17.9617	18.6770	18.6995	18.6778	18.6390	18.9911	18.9758	18.8690	18.8845	18.9852	18.8641	18.8965	18.8711	18.8135	18.9536
Mean	1.8898	1.9001	1.8920	1.8924	1.8398	1.8498	1.7962	1.8677	1.8700	1.8678	1.8639	1.8991	1.8976	1.8869	1.8885	1.8985	1.8864	1.8897	1.8871	1.8814	1.8954
Std. error	0.0009	0.0034	0.0006	0.0036	0.0041	0.0044	0.0040	0.0037	0.0025	0.0057	0.0031	0.0013	0.0028	0.0014	0.0022	0.0008	0.0026	0.0025	0.0048	0.0019	0.0007
Variance	8.16E-06	0.0001	3.54E-06	0.0001	0.0002	0.0002	0.0002	0.0001	6.22E-05	0.0003	9.57E-05	1.73E-05	8.10E-05	1.96E-05	4.73E-05	7.18E-06	6.72E-05	6.46E-05	0.0002	3.61E-05	4.40E-06
Stand. dev	0.0029	0.0109	0.0019	0.0113	0.0130	0.0138	0.0127	0.0118	0.0079	0.0180	0.0098	0.0042	0.0090	0.0044	0.0069	0.0027	0.0082	0.0080	0.0153	0.0060	0.0021
Median	1.8885	1.9077	1.8927	1.8933	1.8445	1.8501	1.7939	1.8677	1.8696	1.8721	1.8673	1.8993	1.9017	1.8880	1.8859	1.8988	1.8846	1.8911	1.8947	1.8829	1.8954
25 prcntil	1.8881	1.8874	1.8900	1.8897	1.8254	1.8423	1.7847	1.8576	1.8634	1.8607	1.8555	1.8950	1.8890	1.8849	1.8821	1.8969	1.8810	1.8858	1.8754	1.8762	1.8946
75 prcntil	1.8917	1.9082	1.8935	1.8990	1.8503	1.8644	1.8067	1.8803	1.8775	1.8776	1.8710	1.9031	1.9048	1.8899	1.8965	1.8997	1.8933	1.8957	1.8968	1.8865	1.8966
Skewness	1.4046	-0.4811	-0.4845	-1.6951	-0.3652	-0.6847	1.0326	-0.0636	-0.0860	-1.1919	-0.7507	-0.4617	-0.4842	-1.4088	0.4784	0.0339	0.6162	-1.3425	-1.3291	-0.6579	-0.7858
Kurtosis	1.7607	-2.1599	-1.2634	4.3739	-1.7134	0.6880	0.5150	-2.1190	-0.7304	0.7436	-0.0447	-1.0291	-1.5083	2.4619	-1.7489	1.9875	-0.2564	1.7482	0.3893	-0.5447	2.0417
Geom. mean	1.8898	1.9001	1.8920	1.8924	1.8397	1.8497	1.7961	1.8677	1.8699	1.8677	1.8639	1.8991	1.8976	1.8869	1.8884	1.8985	1.8864	1.8896	1.8871	1.8813	1.8954
Coeff. var	0.1512	0.5732	0.0995	0.5967	0.7091	0.7456	0.7083	0.6293	0.4218	0.9618	0.5250	0.2189	0.4744	0.2345	0.3643	0.1411	0.4345	0.4255	0.8090	0.3194	0.1107

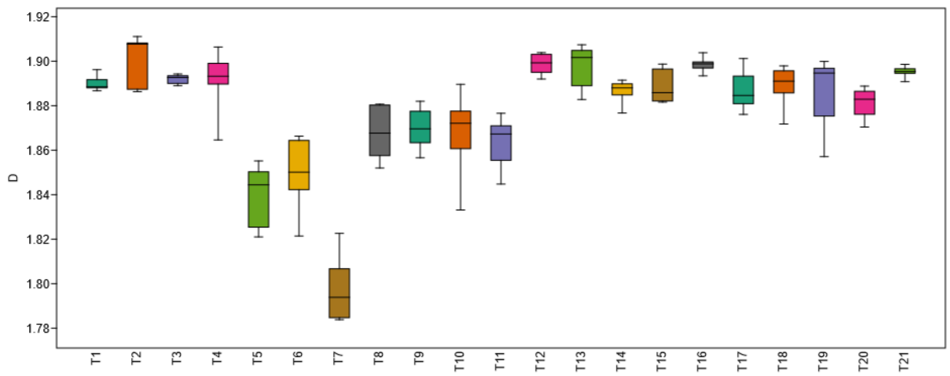

FIG. 2. Fractal dimension distribution in the studied tree species

The recorded data regarding the fractal geometry of the rhytidome (fractal dimension, D) presented statistical safety, and the presence of variance was confirmed in the data set, according to ANOVA Test (Alpha = 0.05), table 2.

TABLE 2. ANOVA Test results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.1250	20	0.0063	66.4001	2.68E-74	1.6264
Within Groups	0.0178	189	9.41E-05			
Total	0.1428	209				

Alpha=0.05

The values of fractal dimension (D) varied between D = 1.7962±0.0040 in case T7 (*Populus alba* L.), and D = 1.9001±0.0034 in case T2 (*Albizia julibrissin* Durazz). The values of fractal dimension showed low variability in all cases, CV = 0.0995 in case T3 (*Carpinus betulus* L.) and CV = 0.9618 in case T10 (*Robinia pseudoacacia* L.). The values of the statistical parameters (table 1) and the graphic distribution (figure 2) indicated differentiated values of the fractal dimensions in the tree species considered in the study. The distribution trend of D values was evaluated by analyzing the entire data series. According to the Mann-Kendall trend test, the statistical reliability of the increasing trend of values in the fractal dimensions (D) data series resulted, with test reliability parameters at the level of S = 3565, Z = 3.5011, and p = 0.00046. The graphical distribution of the data, with the 95% confidence interval, is presented in figure 3, and the distribution of the residual values is shown in figure 4. It was observed that the series of values related to trial T7 (*Populus alba* L.) were positioned outside the confidence interval.

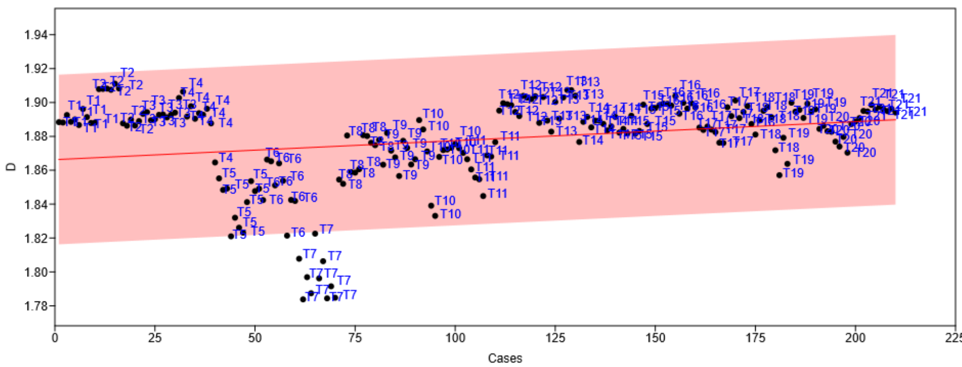

FIG. 3. Trend of the trials distribution, and the 95% confidence interval

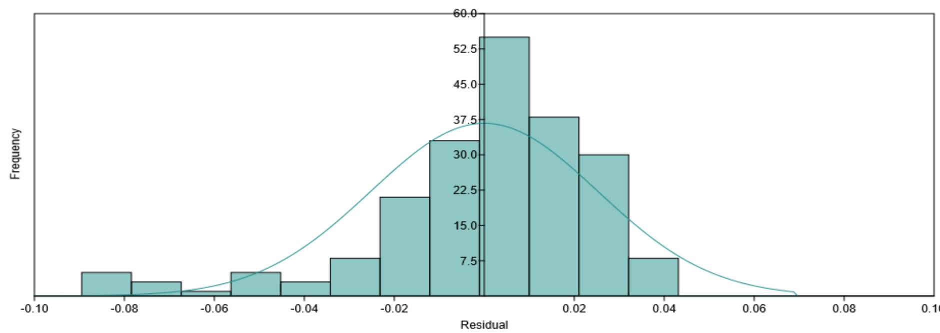

FIG. 4. Graphical distribution of residual values

The possibility of differentiating tree species based on fractal dimensions (D) was evaluated. For this, several tests were successively applied. The ANOVA test (Table 2) confirmed the presence of variance in the data set, which highlighted the difference in the equality of the fractal dimensions' means. The Bayes factor value (6.636E70) confirmed the inequality of the means. The Kruskal-Wallis test confirmed that there was a significant difference between the medians of the D (fractal dimension) values of the samples, with H(chi^2) = 161.3, Hc (tie corrected) = 161.3, and p = 4.14E-24 ($p<0.001$). According to Dunn's post hoc test (Dunn, 1964) the values in Table 3 resulted, which showed the differences between the studied tree species (trials T1 to T21). The fields marked in green in the matrix table (table 3) indicated significant differences between the analyzed tree species based on fractal dimension

(D).

TABLE 3. Dunn's post hoc test results, based on fractal dimension

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21
T1		0.1015	0.5898	0.4256	0.0001	0.0005	1.42E-05	0.0105	0.0135	0.0201	0.0046	0.0417	0.1386	0.5962	0.8902	0.0409	0.6219	0.8324	0.8167	0.1631	0.1739
T2	0.1015		0.2720	0.4004	5.53E-08	3.05E-07	2.26E-09	2.71E-05	4.01E-05	7.45E-05	7.65E-06	0.6897	0.8757	0.0302	0.0758	0.6843	0.0331	0.1539	0.1598	0.0024	0.7811
T3	0.5898	0.2720		0.7967	1.46E-05	5.77E-05	1.06E-06	0.0019	0.0026	0.0042	0.0007	0.1342	0.3462	0.2851	0.4983	0.1323	0.3020	0.7433	0.7586	0.0531	0.4119
T4	0.4256	0.4004	0.7967		4.38E-06	1.87E-05	2.79E-07	0.0008	0.0011	0.0018	0.0003	0.2149	0.4937	0.1846	0.3500	0.2122	0.1971	0.5585	0.5722	0.0284	0.5734
T5	0.0001	5.53E-08	1.46E-05	4.38E-06		0.7544	0.5860	0.2163	0.1846	0.1410	0.3378	5.46E-09	1.31E-07	0.0011	0.0003	5.22E-09	0.0010	6.14E-05	5.64E-05	0.0164	2.53E-07
T6	0.0005	3.05E-07	5.77E-05	1.87E-05	0.7544		0.3912	0.3557	0.3107	0.2464	0.5184	3.40E-08	6.90E-07	0.0031	0.0008	3.26E-08	0.0028	0.0002	0.0002	0.0368	1.28E-06
T7	1.42E-05	2.26E-09	1.06E-06	2.79E-07	0.5860	0.3912		0.0749	0.0613	0.0437	0.1328	1.80E-10	5.83E-09	0.0001	2.64E-05	1.72E-10	0.0001	5.32E-06	4.83E-06	0.0032	1.20E-08
T8	0.0105	2.71E-05	0.0019	0.0008	0.2163	0.3557	0.0749		0.9282	0.8138	0.7811	4.30E-06	5.34E-05	0.0424	0.0155	4.16E-06	0.0388	0.0056	0.0053	0.2442	8.89E-05
T9	0.0135	4.01E-05	0.0026	0.0011	0.1846	0.3107	0.0613	0.9282		0.8844	0.7129	6.61E-06	7.81E-05	0.0525	0.0197	6.38E-06	0.0482	0.0073	0.0069	0.2826	0.0001
T10	0.0201	7.45E-05	0.0042	0.0018	0.1410	0.2464	0.0437	0.8138	0.8844		0.6077	1.30E-05	0.0001	0.0728	0.0288	1.25E-05	0.0671	0.0112	0.0106	0.3528	0.0002
T11	0.0046	7.65E-06	0.0007	0.0003	0.3378	0.5184	0.1328	0.7811	0.7129	0.6077		1.09E-06	1.57E-05	0.0210	0.0070	1.05E-06	0.0191	0.0023	0.0021	0.1492	2.71E-05
T12	0.0417	0.6897	0.1342	0.2149	5.46E-09	3.40E-08	1.80E-10	4.30E-06	6.61E-06	1.30E-05	1.09E-06		0.5784	0.0103	0.0297	0.9941	0.0114	0.0680	0.0711	0.0006	0.4983
T13	0.1386	0.8757	0.3462	0.4937	1.31E-07	6.90E-07	5.83E-09	5.34E-05	7.81E-05	0.0001	1.57E-05	0.5784		0.0443	0.1054	0.5734	0.0484	0.2042	0.2116	0.0040	0.9033
T14	0.5962	0.0302	0.2851	0.1846	0.0011	0.0031	0.0001	0.0424	0.0525	0.0728	0.0210	0.0103	0.0443		0.6951	0.0101	0.9706	0.4584	0.4462	0.3872	0.0588
T15	0.8902	0.0758	0.4983	0.3500	0.0003	0.0008	2.64E-05	0.0155	0.0197	0.0288	0.0070	0.0297	0.1054	0.6951		0.0291	0.7225	0.7267	0.7115	0.2089	0.1342
T16	0.0409	0.6843	0.1323	0.2122	5.22E-09	3.26E-08	1.72E-10	4.16E-06	6.38E-06	1.25E-05	1.05E-06	0.9941	0.5734	0.0101	0.0291		0.0112	0.0669	0.0699	0.0006	0.4937
T17	0.6219	0.0331	0.3020	0.1971	0.0010	0.0028	0.0001	0.0388	0.0482	0.0671	0.0191	0.0114	0.0484	0.9706	0.7225	0.0112		0.4810	0.4685	0.3673	0.0639
T18	0.8324	0.1539	0.7433	0.5585	6.14E-05	0.0002	5.32E-06	0.0056	0.0073	0.0112	0.0023	0.0680	0.2042	0.4584	0.7267	0.0669	0.4810		0.9839	0.1082	0.2509
T19	0.8167	0.1598	0.7586	0.5722	5.64E-05	0.0002	4.83E-06	0.0053	0.0069	0.0106	0.0021	0.0711	0.2116	0.4462	0.7115	0.0699	0.4685	0.9839		0.1038	0.2594

T20	0.1631	0.0024	0.0531	0.0284	0.0164	0.0368	0.0032	0.2442	0.2826	0.3528	0.1492	0.0006	0.0040	0.3872	0.2089	0.0006	0.3673	0.1082	0.1038		0.0059
T21	0.1739	0.7811	0.4119	0.5734	2.53E- 07	1.28E- 06	1.20E- 08	8.89E- 05	0.0001	0.0002	2.71E- 05	0.4983	0.9033	0.0588	0.1342	0.4937	0.0639	0.2509	0.2594	0.0059	

Compared to the mean value of the fractal dimension at the level of the 21 tree species ($\overline{D}$ =0.8781), the difference in fractal dimension for each species was calculated (table 4).

TABLE 4. Statistical significance of differences

Trial	Given mean	Sample mean	95% conf. interval	Difference	95% conf. interval:	t :	p (same mean):
T1	1.8898			0.0117*	(0.00032327 0.023077)	-2.1452	0.0444
T2	1.9001			0.0220***	(0.010623 0.033377)	-4.0338	0.0007
T3	1.8920			0.0139*	(0.0025233 0.025277)	-2.5486	0.0191
T4	1.8924			0.0143*	(0.0029233 0.025677)	-2.6220	0.0163
T5	1.8398			-0.0383^{OOO}	(0.026923 0.049677)	7.0224	<0.001
T6	1.8498			-0.0283^{OOO}	(0.016923 0.039677)	5.1889	<0.001
T7	1.7962			-0.0819^{OOO}	(0.070523 0.093277)	15.0170	<0.001
T8	1.8677			-0.0104^{ns}	(-0.00097673 0.021777)	1.9069	0.0710
T9	1.8700			-0.0081^{ns}	(-0.0032767 0.019477)	1.4852	0.1531
T10	1.8678			-0.0103^{ns}	(-0.0010767 0.021677)	1.8885	0.0735
T11	1.8639	1.8781	(1.8667 1.8895)	-0.0142^{O}	(0.0028233 0.025577)	2.6036	0.0170
T12	1.8991			0.0210**	(0.0096233 0.032377)	-3.8504	0.0010
T13	1.8976			0.0195**	(0.0081233 0.030877)	-3.5754	0.0019
T14	1.8969			0.0188**	(0.0074233 0.030177)	-3.4470	0.0025
T15	1.8885			0.0104^{ns}	(-0.00097673 0.021777)	-1.9069	0.0710
T16	1.8985			0.0204**	(0.0090233 0.031777)	-3.7404	0.0013
T17	1.8864			0.0083^{ns}	(-0.0030767 0.019677)	-1.5218	0.1437
T18	1.8897			0.0116*	(0.00022327 0.022977)	-2.1269	0.0461
T19	1.8871			0.0090^{ns}	(-0.0023767 0.020377)	-1.6502	0.1145
T20	1.8814			0.0033^{ns}	(-0.0080767 0.014677)	-0.6051	0.5519
T21	1.8954			0.0173**	(0.0059233 0.028677)	-3.1720	0.0048

Notes: * – symbol for positive differences; O – symbol for negative differences; ns – no significance of differences; difference thresholds, $p<0.05$, $p<0.01$, $p<0.001$

In relation to the calculated mean value ($\overline{D}$ =0.8781), 14 species with fractal dimension above the mean were recorded, and seven species with fractal dimension below the mean were recorded, under different statistical safety conditions (Table 4).

The cluster analysis grouped the tree species based on similarity, in relation to the fractal dimension (Coph.corr. = 0.948). Within the dendrogram, the independent positioning of trial T7 (*Populus alba* L.) was recorded. This variant presented differences in relation to most of the other species, in conditions of statistical safety (table 3).

Analyzing the results of Dunn's post hoc test (table 3) with the distribution of trials in the cluster dendrogram (figure 5), it was observed that species with a high level of similarity showed reduced differentiation (without statistical safety).

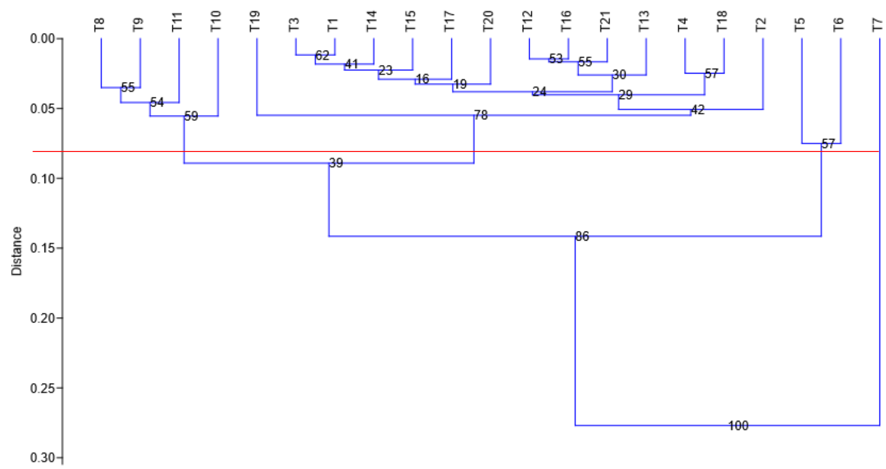

FIG. 5. Cluster dendrogram with species association based on similarity

In the case of trees, the trunk surface was considered fractal, but not the tree trunk volume (Zeide, 1991). Thus, the tree trunk surface (rhytidom geometry) was considered to be able to be analyzed and characterized fractally, and for the height and volume of trees, classical geometry methods were considered adequate (Zeide, 1991). Grigoriev *et al*. (2022) concluded that a tree can be approached by fractal analysis on the dimensional projection of structural elements, although it is not a logarithmic fractal, as a three-dimensional object.

In the present study, fractal analysis showed values of fractal dimension ranging between D = 1.7962±0.0040 in the case of the species *Populus alba* L. (T7), and D = 1.9001±0.0034 in the case of the species *Albizia julibrissin* Durazz (T2).

Fractal analysis has been used to analyze, discriminate, and classify bark surfaces in rubber trees in relation to latex production (Boonprakong and Chamnongthai, 2007). Fractal analysis showed the variation of tree structure in the forest, in relation to the species studied, with the positioning of the trees, their density, intra- and interspecific competition, and the growth rate of the trees (Seidel, 2017).

The description and classification of five apple varieties was possible, in conditions of statistical safety, based on the fractal dimension of the leaves (Sala *et al*., 2017). Based on a study of thousands of tree specimens in various urban environments in the United States, reduced crown fractal dimension was found in relation to water regime and water loss (Arseniou and MacFarlane, 2021). The correlation between fractal dimension and the degree of urbanization level of urban areas was also found

(Arseniou and MacFarlane, 2021). The cluster grouping of some ecotones was obtained based on fractal dimensions, with low fractal dimensions, in the range of 1.018 – 1.154 (Ncube *et al.*, 2025).

In the present study, comparative analysis tests showed the differences between the analyzed tree species, and the level of statistical confidence (table 3). Cluster analysis led to the grouping of the studied tree species, in relation to the degree of similarity based on the fractal dimension of the tree trunk rhytidome. The species *Populus alba* L. (trial T7), with the lowest D value (D = 1.7962±0.0040), was positioned farthest. At the distance level of 0.056 (y axis, figure 5) the other species were grouped into three distinct clusters, based on similarity in relation to the fractal dimension (D).

From the correlated analysis of the results, it was observed that certain tree species studied were statistically significantly differentiated compared to other species, but no species presented significant differentiation compared to all other species.

CONCLUSIONS

Fractal analysis generated fractal dimensions (D) for the characterization of the 21 tree species considered in the study. Fractal dimension values showed low variability within each species, and the dataset presented statistical safety, and a statistically confirmed level of variance.

The increasing variation of fractal dimension (D) in the data set presented statistical safety, according to the Mann-Kendall trend test.

Mathematical and statistical analysis tests confirmed the difference between the mean and median values of the fractal dimension (D) of the considered tree species. Dunn's post hoc test showed the level of statistical confidence in the comparative evaluation of tree species based on fractal dimension, and cluster analysis showed variable levels of similarity between species, based on D values.

The results recorded based on fractal dimensions (D) confirmed the advantages of fractal analysis in comparative studies of tree species in urban environments, and recommend the development of studies for the characterization of trees in relation to environmental conditions specific to the urban ecosystem.

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REFERENCES

- Arseniou G., MacFarlane D.W. 2021. Fractal dimension of tree crowns explains species functional-trait responses to urban environments at different scales. *Ecol. Appl.* 31(4): e02297.

- Boonprakong P., Chamnongthai K. 2007. Bark rubber tree crack detection and classification using fractal dimension. ROCOM'07: *Proceedings of the 7th WSEAS International Conference on Robotics, Control & Manufacturing Technology*, 229–232.
- Bruno O.M., Plotze R.O., Falvo M., Castro M. 2008. Fractal dimension applied to plant identification. *Inf. Sci.* 178(12): 2722–2733.
- Dunn O.J. 1964. Multiple comparisons using rank sums. *Technometrics* 6: 241–252.
- Grigoriev S.V., Shnyrkov O.D., Pustovoit P.M., Iashina E.G., Pshenichnyi K.A. 2022. Experimental evidence for logarithmic fractal structure of botanical trees. *Phys. Rev. E* 105, 044412.
- Guzmán J.A., Sharp I., Alencastro F., Sánchez-Azofeifa G.A. 2020. On the relationship of fractal geometry and tree–stand metrics on point clouds derived from terrestrial laser scanning. *Methods Ecol. Evol.* 11(10): 1309–1318.
- Hai L., Lv Y., Tan S., Feng L. 2023. Study on the influences of the fractal dimension of the root system and slope degree on the slope stability. *Sci. Rep.* 13: 10282.
- Hammer Ø., Harper D.A.T., Ryan P.D. 2001. PAST: Paleontological Statistics software package for education and data analysis. *Palaeontol. Electron.* 4(1): 1–9.
- Hui Z., Cai Z., Xu P., Xia Y., Cheng P. 2023. Tree species classification using optimized features derived from light detection and ranging point clouds based on fractal geometry and quantitative structure model. *Forests* 14(6): 1265.
- Ianovici N, Vereș M., Catrina R.G., Pîrvulescu A.M., Tănase R.M., Datcu D.A 2015. Methods of biomonitoring in urban environment: leaf area and fractal dimension. *Annals of West University of Timişoara, ser. Biology,* 18 (2):169-178.
- Jobin A., Nair M.S., Tatavarti R. 2012. Plant identification based on fractal refinement technique (FRT). *Proc. Technol.* 6: 171–179.
- Murray J., Blackburn G.A., Whyatt J.D., Edwards C. 2018. Using fractal analysis of crown images to measure the structural condition of trees. *Forestry: Int. J. For. Res.* 91(4): 480–491.
- Ncube T.R.L., Lovett J.C., de Klerk H.M., Hui C. 2025. On the fractal dimension of ecotones among African vascular plants. *Ann. Missouri Bot. Gard.* 110: 138–150.
- Pluciński M., Pluciński S., Rodríguez-Iturbe I. 2008. Consequences of the fractal architecture of trees on their structural measures. *J. Theor. Biol.* 251(1): 82–92.
- Rasband W.S. 1997. ImageJ. U. S. National Institutes of Health, Bethesda,Maryland, USA, pp. 1997-2014.
- Sala F., Iordănescu O., Dobrei A. 2017. Fractal analysis as a tool for pomology studies: Case study in apple. *AgroLife Sci. J.* 6(1): 223–233.
- Seidel D. 2017. A holistic approach to determine tree structural complexity based on laser scanning data and fractal analysis. *Ecol Evol*. 8(1): 128–134.
- Vishnu M., Sajeev C.R., Jaishanker R. 2023. Determining the limits of traditional box-counting fractal analysis in leaf complexity studies. *Flora* 304: 152300.
- Voss R. 1985. Random fractal forgeries. In: Earnshaw R. (Ed.) *Fundamental Algorithms For Computer Graphics*, Sringer Verlag, Berlin, pp. 805–835.
- Zeide B. 1991. Fractal geometry in forestry applications. *For. Ecol. Manag*. 46(3-4): 179-188.
- Zhang D., Samal A., Brandle J.R. 2007. A method for estimating fractal dimension of tree crown from digital images. *Int. J. Pattern Recognit. Artif. Intell.* 21(3): 561–572.