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CHARACTERIZATION OF LEAF GEOMETRY AT *Datura stramonium* L. BY IMAGING ANALYSIS

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Abstract

Datura stramonium L. is a species with different active principles, it has toxicity, but it has found certain uses in the pharmaceutical, medicinal, or food field. In certain pedoclimatic conditions it is present in agricultural crops, as a weed. The study analyzed the geometry of the leaves in the species Datura stramonium L. A set of leaves was taken randomly from different specimens of mature plants. The leaves were scanned and analyzed in terms of dimensional parameters (L - length, w - width, Per - perimeter), leaf surface (SLA - scanned leaf area; MLA - measured leaf area), leaf geometry (D - fractal dimension). The experimental data set presented statistical safety, according to the ANOVA test (F> Fcrit, p <0.001, for alpha = 0.001). Very strong and strong correlations were recorded between foliar parameters and SLA, MLA and D respectively (eg r = 0.930 between MLA and L; r = 0.969 between MLA and w; r = 0.946 between Per and SLA; r = 0.933 between D and SLA). Polynomial equations described the interdependence relations between foliar parameters and SLA, MLA and D, in statistical safety conditions (p<0.001).

Key words: *Datura stramonium, fractal geometry, imaging, leaves.*

INTRODUCTION

Datura stramonium L. is an annual species in the Solanaceae family. The species is widespread on the globe, in different ecoclimates (Akbar, 2020). The whole plant (root, stem, leaves, flowers) is toxic, with variations in the level of toxicity depending on the organs of the plant (Trancă et al., 2017).
The herb of *Datura stramonium* L. presents a series of active principles with potential for use in pharmacy and medicine (Li et al., 2012; Soni et al., 2012; Aboluwodi et al., 2017).
The content of active principles in *Datura* was analyzed in the conditions of the plant's relationship with influencing factors, soil, water, nutrients, stress factors etc. (Ali, 1991; Moreno-Pedraza et al., 2019).
Based on the content of bioactive compounds, *Datura stramonium* has been studied as a potential allelopathic effect, in relation to different plant species from spontaneous flora and agricultural crops (Pacanoski et al., 2014).
At the same time *Datura stramonium* L. occurs in different crops, and is approached as a weed (Saayman-duToit, 2000).
The ecological plasticity and the relation of *Datura* plants with ecophysiological factors, with other natural plant species, with nutrients and composition in minerals were studied (Benvenuti and Macchia, 1997; Bhattacharjee et al., 2004; Castillo et al., 2014; Camargi et al., 2017). Studies have been conducted on competition relations between *Datura* plants and different cultivated plant species (Cavero et al., 2002; Karimmojeni et al., 2010).
The effect of different herbicides on *Datura* plants was also analyzed, in order to control weeds in agricultural crops (Sakadzo et al., 2018).
The present study analyzed the species *Datura stramonium* L. to describe models of leaf surface determination and to describe the fractal geometry of the leaves.

MATERIALS AND METHODS

Biological material was represented by the species *Datura stramonium* L. Leaf samples were taken from various mature plants, from the agricultural area adjacent to Timisoara, Timis County.
To obtain the values of dimensional parameters, such as length (L) and width (w), the leaves were measured with an accuracy of ± 0.5 mm.

The leaves were scanned in a 1:1 size ratio. Leaf images were analyzed to obtain datas regarding perimeter (Per) and scanned leaf area (SLA).
The fractal geometry of the leaves was analyzed on binarized images, Figure 1, by the box-counting method (Voss, 1985).

Figure 1. *Datura stramonium* L. leaf sample (binarized image representation)

Experimental data were analyzed to assess the presence of variance and data safety. Also, correlations between determined foliar parameters, interdependence relations, and prediction relations were analyzed. ANOVA test, correlation analysis, regression analysis were used. Correlation and regression coefficients (r, R^2), parameter p and RMSEP were used as parameters for estimating the statistical safety of the results.
ImageJ (Rasband, 1997), PAST (Hammer et al., 2001), and Wolfram Alpha (2020) softwares were used for image analysis and statistical data processing.

RESULTS AND DISCUSSIONS

From the determinations made at the leaf samples, *Datura stramonium* L. species, different values were registered for the leaf length L = 6.90-12.40 ± 0.147 cm, and leaf width w = 4.90-9.70 ± 0.109 cm, for the leaf perimeter Per = 23.273-51.978 ± 0.640 cm, for the scanned leaf area SLA = 17.21-67.38 ± 1.088 cm^2 and for the measured leaf area MLA = 17.25 - 60.14 ± 0.998 cm^2 respectively. The graphic distribution is presented in Figure 2.

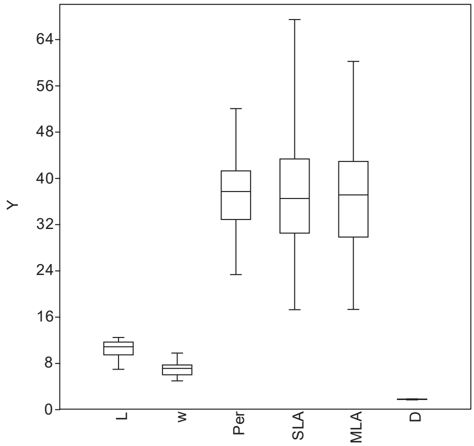

Figure 2. Graphical representation as box-plot type, of the values of the studied foliar parameters of the species *Datura stramonium* L.

The statistical safety of the experimental data and the presence of variance in the data set were evaluated by the ANOVA Test (F> Fcrit; p <0.001), for Alpha = 0.001. The experimental data, in the case of the studied leaf parameters, had a normal distribution.
A non-destructive method, very accessible for determining the leaf area is based on the parameters of the leaves (length - L, width - w). The relationship between L and w leads, in the case of leaves, most frequently to a rectangular geometric surface. The leaf falls within the respective geometric surface, but the relationship requires a correction to render only the actual surface of the leaf. In this sense, a specific correction factor (CF) is required. In order to find out the optimal value of the CF, the model proposed by the Sala et al. (2015) was used. The correction factor has subunit values (CV<1). In the present study, a narrow range (0.45, 0.55) was identified by preliminary calculations. During this interval, calculations were made with a variation of 0.1 units of CF to find the MLA (measured leaf area), relation (1).

$$MLA = L \cdot w \cdot CF \tag{1}$$

The MLA values obtained by calculation were compared with the SLA values, and at CF = 0.50 the minimal errors means (MEM) was registered. This confirmed that the value 0.50 represented the optimal value for CF, Table 1, Figure 3.

Table 1. MLA values in relation to CF for *Datura stramonium* L. leaves

CF values	SLA	MLA	MEM	RMSEP
0.45		32.887	-3.334	4.55600
0.46		33.618	-2.603	3.98023
0.47		34.349	-1.872	3.47484
0.48		35.080	-1.141	3.07473
0.49		35.811	-0.410	2.82497
0.5	**36.221**	**36.542**	**0.321**	**2.76661**
0.51		37.272	1.051	2.91116
0.52		38.003	1.782	3.23153
0.53		38.734	2.513	3.68209
0.54		39.465	3.244	4.22136
0.55		40.196	3.975	4.81966

The RMSEP statistical parameter, relation (3), also confirmed that the value CF = 0.50 represented the optimal value for the correction factor (RMSEP = 2.76661, for CF = 0.50). The RMSEP values for the series of tested CF values, are presented in Table 1.

$$RMSEP = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(y_j - \hat{y}_j\right)^2} \qquad (2)$$

Corresponding to CF = 0.50 value found, and of the measured leaf parameters (L and w), was calculated the value of the MLA (measured leaf area), Table 2. For CF = 0.50 was found MLA = 36.542 cm^2, with MEM = 0.321.
The leaves of the species *Datura stramonium* L. can be described as simple leaves, elliptical in shape, with toothed edges, with alternating arrangement on the plant. Fractal analysis, the box-counting method, was used to describe the geometry of the leaves (Voss, 1985).

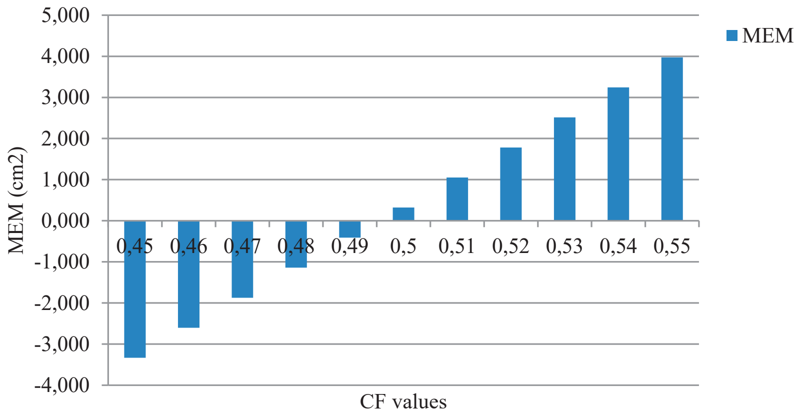

Figure 3. Graphic distribution of MEM, in the calculation of MLA based on CF values, leaf samples *Datura stramonium* L.

The binarized images of the leaf samples were analyzed, in conditions of high statistical safety, R^2 for D = 0.997, SE = 0.004, Table 1.
The average value of the fractal dimension D that described the geometry of the leaves at *Datura stramonium* L. was D = 1.707.
Very strong and strong correlations were recorded between foliar parameters and SLA, MLA and D respectively (eg. r = 0.930 between MLA and L; r = 0.969 between MLA and w; r = 0.946 between Per and SLA; r = 0.933 between D and SLA).
The regression analysis highlighted the close relationship between the leaf parameters L, w and SLA in the variation of the fractal geometry of the leaves, respectively in the definition of the fractal dimension (D).
The fractal dimension D, depending on the foliar parameters L and SLA, was described by equation (3), in conditions of statistical safety of the equation, according to R^2 = 0.999, p <0.001. According to the ANOVA test and the values of the coefficients of equation (3) presented statistical certainty (p << 0.001 for a; p = 0.0408 for b; p << 0.001 for c; p <0.001 for d; p = 0.0011 for e). The 3D graphic distribution is presented in figure 4, and the

distribution in the form of isoquants is shown in figure 5.

$$D_{(L,SLA)} = ax^2 + by^2 + cx + dy + exy + f \quad (3)$$

where: $D_{(L,SLA)}$ - fractal dimension, in relation to L and SLA

x – L; y – SLA;
a, b, c, d, e, f – coefficients of the equation (3);
a= -0.0298384699529701;
b= -0.000190689869023275;
c= 0.445520607743716;
d= -0.0353362346248073;
e= 0.00490581157233495;
f= 0.

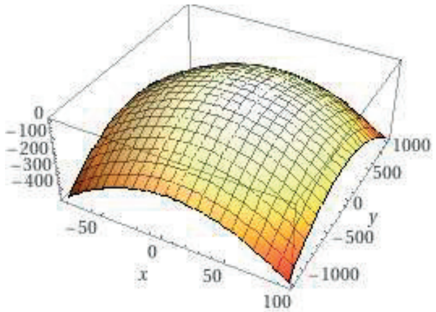

Figure 4. 3D graphical representation of the distribution of the fractal dimension D according to L and SLA, *Datura stramonium* L.

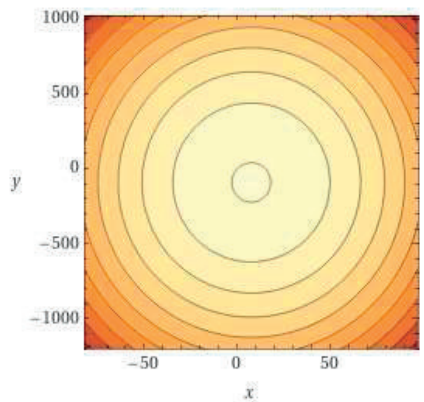

Figure 5. Graphic representation as isoquant of the distribution of the fractal dimension D according to L and SLA, *Datura stramonium* L.

The variation of the fractal dimension D depending on the foliar parameters w and SLA, was described by equation (4), in conditions of general statistical safety of the equation, according to $R^2 = 0.999$, $p < 0.001$. According to the ANOVA test and the values of the coefficients of equation (4) presented statistical safety ($p << 0.001$ for a; $p = 0.00379$ for b; $p << 0.001$ for c; $p < 0.001$ for d; $p < 0.001$ for e). The 3D graphic distribution is presented in figure 6, and the distribution in the form of isoquants is presented in Figure 7.

$$D_{(w,SLA)} = ax^2 + by^2 + cx + dy + exy + f \quad (4)$$

where: $D_{(w,SLA)}$ - fractal dimension in relation to w and SLA

x – w; y – SLA;
a, b, c, d, e, f – coefficients of the equation (4);
a= -0.0993837006585064;
b= -0.000777662962919886;
c= 0.768644952854588;
d= -0.0549306446216847;
e= 0.016679744981095;
f= 0.

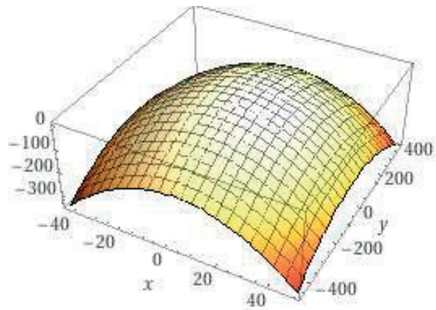

Figure 6. 3D graphical representation of the distribution of the fractal dimension D according to w and SLA, *Datura stramonium* L.

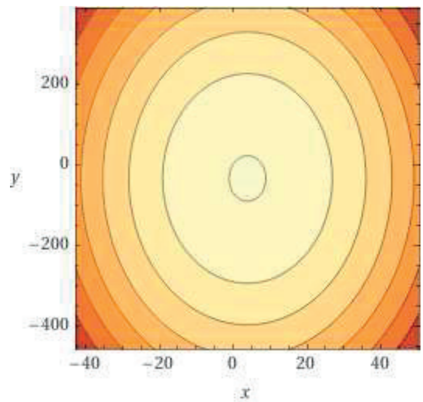

Figure 7. Graphic representation as isoquant of the distribution of the fractal dimension D according to w and SLA, *Datura stramonium* L.

The variation of the fractal dimension D in relation to the foliar parameters Per and SLA, was described by equation (5), in conditions of general statistical safety of the equation, according to $R^2 = 0.999$, $p < 0.001$. According to the ANOVA test and the values of the coefficients of equation (5) presented statistical certainty ($p << 0.001$ for a; $p < 0.001$ for b; $p << 0.001$ for c; $p << 0.001$ for d; $p < 0.001$ for e). The 3D graphic distribution is presented in figure 8, and the distribution in the form of isoquants is presented in Figure 9.

$$D_{(Per,SLA)} = ax^2 + by^2 + cx + dy + exy + f \quad (5)$$

where: $D_{(Per,SLA)}$ - fractal dimension in relation to Per and SLA

x – Per; y – SLA;
a, b, c, d, e, f – coefficients of the equation (5);
a= -0.00477548971090102;
b= -0.00133694153031225;
c= 0.170424058654503;
d= -0.0793952105658202;
e= 0.00492200264906732;
f= 0.

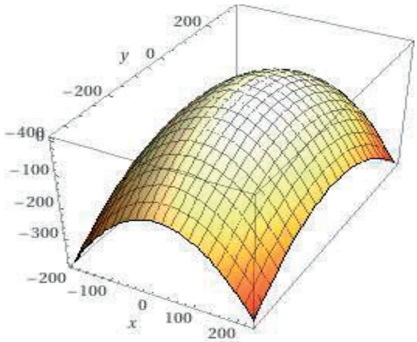

Figure 8. 3D graphical representation of the distribution of the fractal dimension D according to Per and SLA, *Datura stramonium* L.

Analyzing the foliar parameters studied in terms of coefficient of variation (CV), high values were found for SLA (CV_{SLA} = 30.0438) and MLA (CV_{MLA} = 27.3120), moderate values in the case of L (CV_L = 14.2455), w (CV_w = 15.6528) and Per (CV_{Per} = 17.5079). Low value of the coefficient of variation were recorded in the case of fractal dimension D (CV_D = 2.4234).

Variations in plant leaves are generated by complex causes, such as the relationship of plants with natural and anthropogenic environmental factors (Datcu et al., 2017; Li et al., 2018; Liu et al., 2019), by foliar treatments, cultivation and growth conditions (Rawashdeh and Sala, 2014; del Pazo et al., 2020; Ren et al., 2020), by stress factors (Poorter et al., 2009) etc.

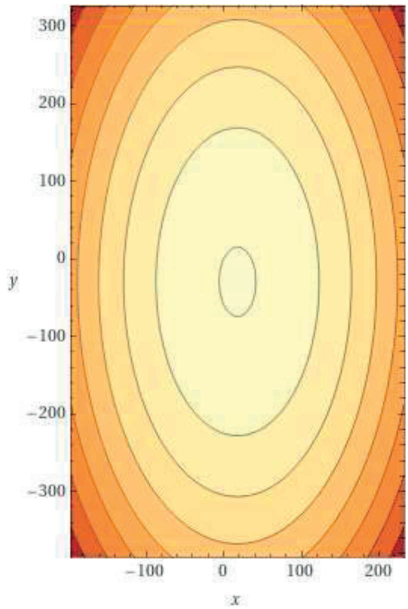

Figure 9. Graphic representation as isoquant of the distribution of the fractal dimension D according to Per and SLA, *Datura stramonium* L.

Imaging analysis is a very useful method for the study of plants at the foliar level, the whole plant, or plant associations (natural or anthropogenic ecosystems) due to the various approaches and facilities it offers; obtaining results in real time (or very short compared to classical methods), has applicability on mobile devices, high portability etc. It also allows integration into complex analysis schemes, and association with various image capture devices (Li et al., 2014; Komis et al., 2018; Beć et al., 2020).

Imaging analysis has been used for studies of leaf structure and morphology (Mathers et al., 2018), plant phenotyping (Li et al., 2014; Rousseau et al., 2015), analysis of physiological indices (Drienovsky et al., 2017a; Constantinescu et al., 2018), detection of symptoms at the foliar level and plant diseases (Drienovsky et al., 2017b; Veys et al., 2019; Singh et al., 2020), characterization of biomass in agricultural crops (Pandey et al., 2017) etc.

In the present study, based on the CV values resulting from the analysis of the leaf samples for the species *Datura stramonium* L., it can be appreciated that for the description of the leaf geometry the greatest stability was presented by the fractal dimension (D). Similar results were reported by Sala et al. (2020a) for the black alder.

Similar studies have been conducted for the analysis of leaf fractal geometry and characterization of some plant species (Backes et al., 2009; Du et al., 2013; Gazda, 2013; Da Silva et al., 2015), and for the analysis and classification of five varieties of apple, based on the fractal geometry of the leaves (Sala et al., 2017).

Fractal analysis was used to describe the geometry of the ash tree rhytidome, and based on the fractal dimensions, a variation model was performed in relation to the shooting distance (Nicolin et al., 2019).

The geometry of some wheat plant associations, at the level of wheat crops, was studied by fractal analysis, in order to classify 10 wheat varieties (Rujescu et al., 2020). The method used facilitated the analysis and classification of the varieties studied, in conditions of statistical safety.

In the analysis of the degree of spatial variability of agricultural lands, fractal analysis led to the development of variation models based on the values of fractal dimensions D resulting from imaging analysis (Sala et al., 2020b).

The results obtained in the present study fall within the general and specific context of the studied bibliographic sources for the scientific substantiation of this research and bring information on the particular geometry of the leaves to the analysed specie, *Datura stramonium* L.

CONCLUSIONS

To find the leaf area at *Datura stramonium* L. by non-destructive methods, based on the leaf parameters L and w (measured leaf area - MLA) the value of the correction factor was found, CF = 0.50. This facilitated the finding of MLA values with high accuracy and in statistical safety conditions.

The description of the leaf geometry was possible by fractal analysis (D = 1.707), of the leaf samples taken in the study.

Very strong correlations were identified between foliar parameters of the leaves and elements of the geometry of the studied leaves (SLA, MLA, D). Mathematical models were found that described the interdependence relationships between stdiati foliar parameters and fractal dimension D.

REFERENCES

Aboluwodi, A.S., Avoseh, O.N., Lawal, O.A., Ogunwande, I.A., Giwa, A.A. (2017). Chemical constituents and anti-inflammatory activity of essential oils of *Datura stramonium* L. *Journal of Medicinal Plants Studies*, *5*(1), 21–25.

Akbar, S. (2020). *Datura stramonium* L. (Solanaceae). In: Handbook of 200 Medicinal Plants, Springer pp. 857–868.

Ali, R.M. (1991). Changes in chemical composition of fruits of salinized *Datura stramonium*. *Journal of Islamic Academy of Sciences*, *4*(4), 289–292.

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.

Beć, K.B., Grabska, J., Bonn, G.K., Popp, M., Huck, C.W. (2020). Principles and applications of vibrational spectroscopic imaging in plant science: A Review. *Frontiers in Plant Science*, *11*. 1226.

Benvenuti, S., Macchia, M. (1997). Light environment, phytochrome and germination of *Datura stramonium* L. seeds. *Environmental and Experimental Botany*, *38*(1), 61–71.

Bhattacharjee, S., Kar, S., Chakravarty, S. (2004). Mineral compositions of *Datura*: A traditional Tropical medicinal plant. *Communications in Soil Science and Plant Analysis*, *35*(7), 937–946.

Camargi, I.D., Nattero, J., Careaga, S.A., Núñez-Farfán, J. (2017). Flower-level developmental plasticity to nutrient availability in *Datura stramonium*: implications for the mating system. *Annals of Botany*, *120*(4), 603–615.

Castillo, G., Cruz, L.L., Tapia-López, R., Olmedo-Vicente, E., Carmona, D., Anaya-Lang, A.L., Fornoni, J., Andraca-Gómez, G., Valverde, P.L., Núñez-Farfán, J. (2014). Selection mosaic exerted by specialist and generalist herbivores on chemical and physical defense of *Datura stramonium*. *PLoS One*, *9*(7), e102478.

Cavero, J., Zaragoza, C., Suso, M.L., Pardo, A. (2002). Competition between maize and *Datura stramonium* in an irrigated field under semi-arid conditions. *Weed Research*, *39*(3), 225–240.

Constantinescu, C., Herbei, M., Rujescu, C., Sala, F. (2018). Model prediction of chlorophyll and fresh biomass in cereal grasses based on aerial images. *AIP Conference Proceedings*, 1978, 390003.

Da Silva, N.R., Florindo, J.B., Gómez, M.C., Rossatto, D.R., Kolb, R.M., Bruno, O.M. (2015). Plant identification based on leaf midrib cross-section images using fractal descriptors. *PLoS ONE*, *10*(6), e0130014.

Datcu, A.-D., Sala, F., Ianovici, N. (2017). Studies regarding some morphometric and biomass allocation parameters in the urban habitat on *Plantago major*. *Research Journal of Agricultural Science*, *49*(4), 96–102.

Del Pozo, A., Méndez-Espinoza, A.M., Romero-Bravo, S., Garriga, M., Estrada, F., Alcaíno, M., Camargo-Rodriguez, A.V., Corke, F.M.K., Doonan, J.H., Lobos, G.A. (2020). Genotypic variations in leaf and whole-plant water use efficiencies are closely related in bread wheat genotypes under well-watered and water-limited conditions during grain filling. *Scientific Report, 10*. 460.

Drienovsky, R., Nicolin, A.L., Rujescu, C., Sala, F. (2017a). Scan LeafArea – A software application used in the determination of the foliar surface of plants. *Research Journal of Agricultural Science*, *49*(4), 215–224.

Drienovsky, R., Nicolin, A.L., Rujescu, C., Sala, F., (2017b). Scan Sick & Healthy Leaf – A software application for the determination of the degree of the leaves attack. *Research Journal of Agricultural Science*, *49*(4), 225–233.

Du, J.-x., Zhai, C.-M., Wang, Q.-P. (2013). Recognition of plant leaf image based on fractal dimension features. *Neurocomputing*, *116*. 150–156.

Gazda, A. (2013). Fractal analysis of leaves: are all leaves self-similar along the cane? *Ekológia (Bratislava)*, *32*(1), 104–110.

Hammer, Ø., Harper, D.A.T., Ryan, P.D. (2001). PAST: Paleontological Satistics software package for education and data analysis. *Palaeontologia Electronica*, *4*(1), 1–9.

Karimmojeni, H., Mashhadi, H.R., Shahbazi, S., Taab, A., Alizadeh, H.M. (2010). Competitive interaction between maize, *Xanthium strumarium* and *Datura stramonium* affecting some canopy characteristics. *Australian Journal of Crop Sciences*, *4*(9), 684–691.

Komis, G., Novák, D., Ovečka, M., Šamajová, O., Šamaj, J. (2018). Advances in imaging plant cell dynamics. *Plant Physiology*, *176*. 80–93.

Li, J., Lin, B., Wang, G., Gao, H., Qin, M. (2012). [Chemical constituents of Datura stramonium seeds]. *Zhongguo Zhong Yao Za Zhi*, *37*(3), 319–22. Chinese. PMID: 22568232.

Li, L., Zhang, Q., Huang, D. (2014). A review of imaging techniques for plant phenotyping. *Sensors*, *14*(11), 20078–10111.

Li, Y., He, N., Hou, J., Xu, L., Liu, C., Zhang, J., Wang, Q., Zhang X., Wu, X. (2018). Factors influencing leaf chlorophyll content in natural forests at the biome scale. *Frontiers in Ecology and Evolution*, *6*. 64.

Liu, C., Li, Y., Xu, L., Chen, Z., He, N. (2019). Variation in leaf morphological, stomatal, and anatomical traits and their relationships in temperate and subtropical forests. *Scientific Reports*, *9*. 5803.

Mathers, A.W., Hepworth, C., Baillie, A.L., Sloan, J., Jones, H., Lundgren, M., Fleming, A.J., Mooney, S.J., Sturrock, C.J. (2018). Investigating the microstructure of plant leaves in 3D with lab-based X-ray computed tomography. *Plant Methods*, *14*. 99.

Moreno-Pedraza, A., Gabriel, J., Treutler, H., Winkler, R., Vergara, F. (2019). Effects of water availability in the soil on tropane alkaloid production in cultivated *Datura stramonium*. *Metabolites*, *9*(7), 131.

Nicolin, L.A., Popescu, C.A., Rujescu, I.C., Herbei, V.M., Sala, F. (2019). Fractal characterisation of the cork cambium in *Fraxinus angustifolia* Vahl. depending on image caption distance. *AIP Conference Proceedings*, 2116, 370005.

Pacanoski, Z., Velkoska, V., Týr, Š. (2014). Allelopathic potential of Jimsonweed (*Datura stramonium* L.) on the early growth of maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.). *Journal of Central European Agriculture*, *15*(3), 1980208.

Pandey, P., Ge, Y., Stoerger, V., Schnable, J.C. (2017). High throughput *In vivo* analysis of plant leaf chemical properties using hyperspectral imaging. *Frontiers in Plant Science*, *8*. 1348.

Poorter, H., Niinemets, Ü., Poorter, L., Wright, I.J., Villar, R. (2009). Causes and consequences of variation in leaf mass per area (LMA): a meta-analysis. *New Phytologist*, *182*(3), 565–588.

Rasband, W.S. (1997). ImageJ. U. S. National Institutes of Health, Bethesda, Maryland, USA, pp. 1997-2014.

Rawashdeh, H.M., Sala, F. (2014). Foliar application of boron on some yield components and grain yield of wheat. *Academic Research Journal of Agricultural Science and Research*, *2*(7), 97–101.

Ren, J., Ji, X., Wang, C., Hu, J., Nervo, G., Li, J. (2020). Variation and genetic parameters of leaf morphological traits of eight families from *Populus simonii* × *P. nigra*. *Forest*, *11*. 1319.

Rousseau, D., Chéné,Y., Belin, E., Semaan, G., Trigui, G., Boudehri, K., Franconi, F., Chapeau-Boldeau, F. (2015). Multiscale imaging of plants: current approaches and challenges. *Plant Methods*, *11*. 6.

Rujescu, C., Popescu, C., Rawashdeh, H., Sala, F. (2020). Imagistic technique and fractal analysis - Investigations mechanisms of the morphological and temporal variability of the wheat cultures. *Tehnicki Vjesnik-Technical Gazette*, *27*(5), 1472–1477.

Saayman-duToit, A.E.J. (2000). Effect of plant density, weed-crop interference and water stress on seed germination of *Datura stramonium* L. *South African Journal of Plant and Soil*, *17*(3), 113–116.

Sakadzo, N., Pahla, I., Muzemu, S., Mandumbu, R., Makaza, K. (2018). Herbicidal effects of *Datura stramonium* (L.) leaf extracts on *Amaranthus hybridus* (L.) and *Tagetes minuta* (L.). *African Journal of Agricultural Research*, *13*(34), 1754–1760.

Sala, F., Arsene, G.-G., Iordănescu, O., Boldea, M. (2015). Leaf area constant model in optimizing foliar area measurement in plants: A case study in apple tree. *Scientia Horticulturae*, *193*, 218–224.

Sala, F., Iordănescu, O., Dobrei, A. (2017). Fractal analysis as a tool for pomology studies: Case study in apple. *AgroLife Scientific Journal*, *6*(1), 224–233.

Sala, F., Datcu, A.-D., Rujescu, C. (2020a). Fractal dimension and causality relationships with foliar parameters: Case study at *Alnus glutinosa* (L.) GAERTN. *Annals of West University of Timişoara, Ser. Biology*, *23*(1), 73–82.

Sala, F., Popescu, C.A., Herbei, M. (2020b). Fractal analysis in estimating the fragmentation degree of agricultural lands. *Scientific Papers: Management, Economic Engineering in Agriculture & Rural Development*, *20*(3), 517–524.

Singh, V., Sharma, N., Singh, S. (2020). A review of imaging techniques for plant disease detection. *Artificial Intelligence in Agriculture*, *4*, 229–242.

Soni, P., Siddiqui, A.A., Dwivedi, J., Soni, V. (2012). Pharmacological properties of *Datura stramonium* L. as a potential medicinal tree: An overview. *Asian Pacific Journal of Tropical Biomedicine*, *2*(12), 1002–1008.

Trancă, S.D., Szabo, R., Cociș, M. (2017). Acute poisoning due to ingestion of *Datura stramonium* – a case report. *Romanian Journal of Anaesthesia and Intensive Care*, *24*(1), 65–68.

Veys, C., Chatziavgerinos, F., AlSuwaidi, A., Hibbert, J., Hansen, M., Bernotas, G., Smith, M., Yin, H., Rolfe, S., Grieve, B. (2019). Multispectral imaging for presymptomatic analysis of light leaf spot in oilseed rape. *Plant Methods*, *15*, 4.

Voss, R. (1985). Random fractal forgeries. In: Earnshaw R. (Ed.) Fundamental algorithms for computer graphics, Sringer Verlag, Berlin, pp. 805-835.

Wolfram, Research, Inc., Mathematica, Version 12.1, Champaign, IL (2020).