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# Fractal analysis in the study of the flowers shape in the species *Leontopodium alpinum* Cass.

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**Abstract**
Fractal analysis was used to study the shape of flowers in the species *Leontopodium alpinum* Cass. Twenty-five herborized flowers were analyzed. The flowers were scanned (front side - FS, and back side - BS) to obtain the images and analyze the shape through fractal analysis. The binarized images were analyzed and the parameter values were obtained: total pixels (TP), foreground pixels (FP), fractal dimension (D). The ratio FP-FS/TP, and FP-BS/TP was calculated, and resulted FP-FS/TP = 0.0056, respectively FP-BS/TP = 0.0059 (mean values). The fractal dimension depending on the flower scan (front and back flower image) varied between D-FS = 1.178 – 1.489±0.023, respectively D-BS = 1.190 – 1.501±0.022. The difference between the mean values of D-FS and D-BS (0.015) falls within the limits of standard errors (SE). The coefficient of variation (CV) in the case of D-FS was $CV_{D\text{-}FS}$ = 8.797, and in the case of D-BS it was $CV_{D\text{-}BS}$ = 8.265. The comparative analysis between the data series regarding the fractal dimension (D-FS, D-BS) led to differences without statistical significance ($p>0.05$), which indicated the similarity of the two data series.

**Keywords:** flower shape, fractal analysis, fractal geometry, herborized flowers, *Leontopodium*

## Introduction

The geometry of flower shapes in plants has been studied from different perspectives, morpho-anatomical and functional, in relation to plant species as evolutionary adaptation, as well as in relation to different biotic and abiotic influencing factors [4].

Leaves and flowers were used as indicators for the differentiation of plant species within protected areas, through imaging analysis [6]. Based on the recorded data (morphometric geometry, leaves and flowers) and through appropriate statistical analysis (discriminant function analysis, canonical variable analysis), the authors have clearly identified the species considered in the study. Specific flower parameters (shape, size, color, etc.) have been studied in relation to the diversity of plant species and reproductive isolation [21]. The authors of the study have variations of the floral parameters studied in relation to the geographical distribution, with relief and climatic factors.

Souza et al. (2022) [20] studied flower color intensity in relation to plant crop, based on an innovative predictive solution. The authors used image analysis methods, combined with algorithms and modeling to study the flowers of the species Portulaca umbraticola, with three types of flowers (white, yellow, and red). Fractal analysis was used in the study of flower architecture. The authors recorded the association of flower color intensity with the degree of compactness of flower architecture. Also, the authors concluded the importance of the approach method for horticultural practice, in relation to certain objectives for ornamental plants.

Based on some studies on brown algae (three species) in different stages of growth, the fractal dimension was considered a quantitative measure for evaluating the complexity of the form in plants, associated with the growth and development of plants [10]. The authors reported the increase in the fractal dimension (from 1 to 1.6) associated with the development of algae, during the study period.
Fractal analysis was used in the study of spatio-temporal variability of plant populations [1]. The authors concluded that the informational fractal dimension was a good indicator to estimate disturbances at the ecosystem level.

The identification of some plant species was done through the fractal analysis of the complexity of the leaves [5]. Fractal analysis has been used in numerous studies on plants, and fractals have been considered in nature as the result of a growth process [8]. In the study of 50 plant species, with 10 samples per set, Jobin et al. (2012) [15] proposed an algorithm for identification and classification of plant species through fractal analysis. The authors analyzed the fractal dimensions for outline, outline - ribs, and ribs, and obtained an accuracy rate of 84%.

The structure of the flowers was analyzed by modeling, based on observations and statistics [9]. Based on the technology specific to fractal graphics, the author generated flower models with a high realistic level.
Imaging analysis, in combination with genetic analysis, was used to study the salt tolerance of some plant species [7]. Fractal analysis was used in the study and the authors communicated that the fractal dimension (FD), together with other imaging indicators, facilitated the detection of the response of plants as adaptation to the saline environment. The authors reported a negative correlation between FD and certain plant compounds, in response to saline stress (e.g. hydrogen peroxide). The fractal dimension was a relevant indicator, together with other morphological indicators, to describe the plant architecture in relation to the saline environment, the PCA analysis seems to have safely discriminated the results.

In the study of ten classical gardens, fractal analysis facilitated the quantitative description of the level of complexity and diversity [11]. The authors communicated the variation of the fractal dimension in relation to the plant genotypes and the arrangement modules in the analyzed space. Structures and forms of plant organisms, which present self-repeating (similar) patterns at all scales of approach, have been studied by fractal analysis [3].

The present study used fractal analysis to characterize the shape of flowers in the species *Leontopodium alpinum* Cass., based on herborized flowers and scanned from the front side and back side position.

**Material and Method**

For the fractal characterization of flower geometry in the species *Leontopodium alpinum* Cass., herborized and dried flowers were used. The flower samples came from *Leontopodium* plants purchased from Bauhaus-Zagreb, August 2023, and grown in the private garden. 25 flowers were taken at random and were herborized. The herborization was done by freely arranging the flower organs on the paper sheet, without the intervention of directing them in a certain position. To obtain the images of the flowers, each flower was scanned in a 1:1 ratio. Each flower was scanned on the front side of the flower (front side - FS) and the back side (BS). A series of 50 images resulted (sample in figure 1).

**(a)** **(b)**

**Figure 1. Example of images of flowers studied in *Leontopodium alpinum* Cass. species (herborized flowers);**
**(a) front side - FS, (b) back side - BS**

The binarized images were analyzed by the box-counting method [22], [18]. The results were the values for the parameters: total pixels (TP), foreground pixelx (FP), and respectively for the fractal dimension (D). The determinations were made for the two categories of image series (FS, BS), and the parameters were noted appropriately: TP; FP-FS, FP-BS; D-FS, D-BS.

The data obtained from the fractal analysis were statistically analyzed to describe the data series based on the descriptive statistics parameters. A comparative analysis was made between the two series of data. Adequate statistical parameters were used to assess the reliability of the recorded results. Appropriate mathematical and statistical analysis tools were used [13], [14].

**Results and Discussion**

The images resulting from scanning the herborized flowers of *Leontopodium alpinum* Cass. (50 images, 25 front side, and 25 back side) were analyzed to obtain the fractal characterization data. Two data sets resulted for the fractal dimension (D) and foreground pixels (FP). Based on the FP-FS and FP-BS values, the ratios were calculated in relation to the TP (total pixels) of the images. The data series were analyzed on the two categories of images (FF, BF) and the values of the statistical parameters are presented in table 1. The recorded experimental data showed statistical reliability, according to table 2.

**Table 1. Statistical values for fractal analysis of flower images in *Leontopodium alpinum* Cass. species**

| Statistical parameters | TP | Front flower shapes | | | Back flower shapes | | |
|---|---|---|---|---|---|---|---|
| | | FP-FS | FP-FS/TP | D-FS | FP-BS | FP-BS/TP | D-BS |
| N | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Min | 3974600 | 1.4943 | 0.0028 | 1.178 | 1.6524 | 0.0029 | 1.190 |
| Max | 3974600 | 35414 | 0.0089 | 1.489 | 36935 | 0.0093 | 1.501 |
| Sum | 9.94E+07 | 541590.5 | 0.1400 | 33.187 | 554137.4 | 0.1481 | 33.552 |
| Mean | 3974600 | 21663.62 | 0.0056 | 1.327 | 22165.5 | 0.0059 | 1.342 |
| Std. error | 0 | 1720.591 | 0.0004 | 0.023 | 1995.686 | 0.0004 | 0.022 |
| Variance | 0 | 7.40E+07 | 0.0000 | 0.014 | 9.96E+07 | 0.0000 | 0.012 |
| Stand. dev | 0 | 8602.957 | 0.0019 | 0.117 | 9978.431 | 0.0019 | 0.111 |
| Median | 3974600 | 21496 | 0.0054 | 1.382 | 22900 | 0.0058 | 1.407 |
| 25 prcntil | 3974600 | 15953 | 0.0040 | 1.207 | 15549 | 0.0043 | 1.231 |
| 75 prcntil | 3974600 | 29393 | 0.0074 | 1.447 | 30798 | 0.0078 | 1.448 |
| Geom. mean | 3974600 | 14538.79 | 0.0053 | 1.323 | 10663.78 | 0.0056 | 1.338 |
| Coeff. var | 0 | 39.71154 | 33.6117 | 8.797 | 45.01785 | 32.5848 | 8.265 |

**Table 2. ANOVA Test**

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 1.7E+10 | 5 | 3.4E+09 | 150.5682 | 2.33E-55 | 2.277044 |
| Within Groups | 3.25E+09 | 144 | 22557556 | | | |
| Total | 2.02E+10 | 149 | | | | |

The values of the fractal dimensions (D), results for the two series of images (D-FS, D-BS) presented a normal distribution, figure 2.

Correlation analysis between fractal characterization parameters of flower shape (front side, and back side) in the species *Leontopodium alpinum* Cass. led to the data presented in table 3. It was found that in all cases there were positive correlations, and the values of the correlation coefficient showed statistical certainty. The two values of the fractal dimension (D-FS, and D-BS) showed a very strong positive correlation, $r=0.992^{***}$ ($p< 0.001$). This indicates a very good expression of the fractal geometry of the flowers, in both cases of analysis (FS, BS).

In the case of the analysis of the front side images, the average value of the fractal dimension D-FF = 1.327±0.023 resulted, and in the case of the analysis of the back-side flower images, the average value of the fractal dimension D-BF = 1.342±0.022 resulted. The difference between the two average values was 0.015, a value that fell within the limits of the standard error. Therefore, it was considered that any of the two series of images (front flower, back flower) can be used to obtain the fractal dimension to characterize the shape of

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flowers in the species Leontopodium alpinum Cass.

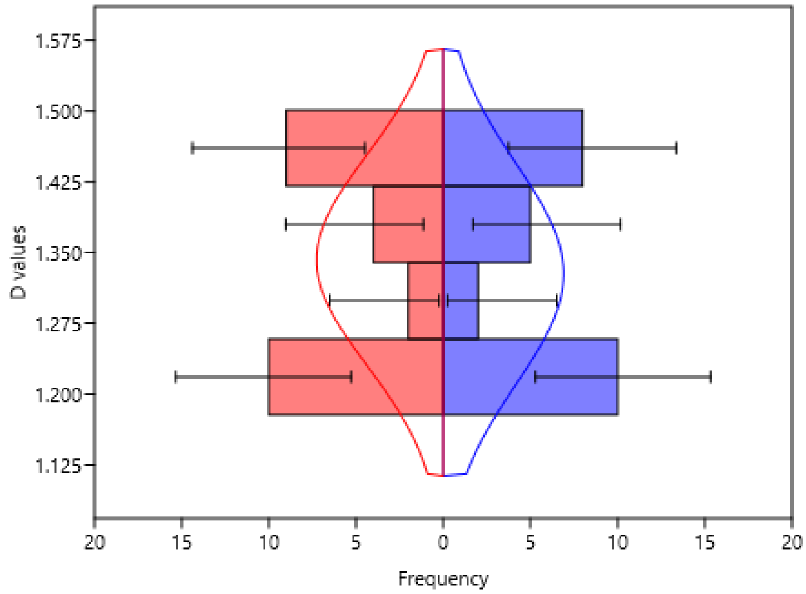


**Figure 2. Distribution histograms for fractal dimension (D) in relation to front side flower shape (D-FS, blue color) and back side flower shape (D-BS, red color), *Leontopodium alpinum* Cass.**

Additionally, the data series were analyzed for each parameter resulting from the fractal analysis, in the case of FF and BF images. The results of the comparative analysis are presented in table 4. It was found that the differences did not show statistical certainty, so it can be considered that both sources of images can characterize the shape of the flowers in the species Leontopodium alpinum Cass. as precisely.

**Table 3. Correlation table between fractal geometry parameters of *Leontopodium alpinum* Cass. flowers**

| Variable | | FP-FS | FP-FS/TP | D-FS | FP-BS | FP-BS/TP | D-BS |
|---|---|---|---|---|---|---|---|
| FP-FS | Pearson's r | — | | | | | |
| | p-value | — | | | | | |
| FP-FS/TP | Pearson's r | 0.940*** | — | | | | |
| | p-value | < .001 | — | | | | |
| D-FS | Pearson's r | 0.746*** | 0.751*** | — | | | |
| | p-value | < .001 | < .001 | — | | | |
| FP-BS | Pearson's r | 0.811*** | 0.883*** | 0.611** | — | | |
| | p-value | < .001 | < .001 | 0.001 | — | | |
| FP-BS/TP | Pearson's r | 0.935*** | 0.997*** | 0.755*** | 0.887*** | — | |
| | p-value | < .001 | < .001 | < .001 | < .001 | — | |
| D-BS | Pearson's r | 0.737*** | 0.764*** | 0.992*** | 0.622*** | 0.773*** | — |
| | p-value | < .001 | < .001 | < .001 | < .001 | < .001 | — |

The level of correlation recorded between the parameters related to the fractal geometry of the flowers, obtained by the two methods of scanning the flowers (FS, BS), showed the high level of description of the shapes of the flowers, in conditions of statistical safety (p<0.001). The values of the fractal dimension, based on the two categories of images (D-FS, D-BS) presented differences at the level of 0.015, which fell within the standard error. This confirmed the impartiality of the fractal analysis in relation to the two scanning positions of the flowers (FS, BS).

Some studies have highlighted certain possible limitations in traditional fractal analysis (based on box-counting), considering that this type of analysis would not capture the lacunarity observed on the edges of the leaves [17].

**Table 4. The values of the comparative analysis tests of front and back flower images in the *Leontopodium alpinum* Cass. species**

| Statistical Parameters | FP | FP/TP | D |
|---|---|---|---|
| Given mean: | 21663.62 | 0.0056 | 1.327 |
| Sample mean: | 22165 | 0.005922 | 1.342 |
| 95% conf. interval: | (18047 26284) | (0.0051255 0.0067185) | (1.2963 1.3879) |
| Difference: | 501.88 | 3.22E-04 | 0.01508 |
| 95% conf. interval: | (-3617 4620.8) | (-0.00047453 0.0011185) | (-0.030709 0.060869) |
| t: | 0.25148 | 0.83434 | 0.67972 |
| p (same mean): | 0.80358 | 0.41232 | 0.50319 |
| Significance of the mean differences | nd | nd | nd |
| Given median: | 21496 | 0.0054 | 1.382 |
| Sample median: | 22900 | 0.00576 | 1.407 |
| W: | 187 | 208 | 232 |
| Normal appr. z: | 0.65922 | 1.2243 | 1.8703 |
| p (same median): | 0.50975 | 0.22085 | 0.061444 |
| Significance of the median's differences | nd | nd | nd |

At the same time, however, fractal analysis is promoted in different fields of study, which highlighted the importance in choosing the appropriate method in relation to the purpose of the study, experiments and research [23]. SEM images were analyzed by fractal analysis in order to characterize nanocomposite materials [12]. The author communicated the highlighting through fractal analysis of a dimensional and morphological variation of the particles, although their dispersion was uniform on all surfaces. The author concluded the importance of fractal analysis, associated with SEM (and other types of images) for in-depth studies and NMR applications.

Fractal analysis was used for tree vegetation studies, as a response and adaptation of tree vegetation to the urban environment [2].

Fractal analysis was used to study the geometry of the shape of apple leaves, and based on the results it was possible to differentiate five varieties, with statistical certainty, Coph. Corr = 0.967 [19].

Non-destructive methods, based on imaging analysis and fractal analysis to evaluate the adaptation and response of some halophyte plant species under saline stress conditions [7].

Fractal analysis associated with Machine Learning was used in rice studies to accurately assess plant growth stages and quantify the degree of heterogeneity of fractal dimensions [16]. The authors considered the formation of groups of fractal dimension values for a more precise association with plant growth stages.

In the present study, a variation of the fractal dimension was observed for each of the two ways of analyzing the shape of the flowers (FS, and BS). In both cases, a correlation of D values (D-FS, D-BS) with FP (FP-FS, FP=BS) was found, under statistical safety conditions ($p<0.001$). In the case of D-FS, there were correlations at the level of $r = 0.746^{***}$ with FP-FS, and correlations at the level of $r = 0.751^{***}$ with the ratio FP-FS/TP. In the case of D-BS, there were correlations at the level of $r = 0.622^{***}$ with FP-BS, respectively correlation at the level of $r = 0.773^{***}$ with the ratio FP-BS/TP.

## Conclusions

Fractal analysis facilitated the investigation of the shape of the flowers in the species *Leontopodium alpinum* Cass., based on images obtained by scanning herborized flowers, front side (FS) and back side (BS). The fractal dimensions for the two series of images (D-FS, D-BS) showed normal distribution.

The fractal dimension for the two data series (D-FS, D-BS) showed a very strong positive correlation, $r = 0.992^{***}$ ($p<0.001$).

From the comparative analysis of the data series, for the parameters considered in the fractal analysis (FP-FS, FP-FS/TP, D-FS; FP-BS, FP-BS/TP, D-BS) it was found that the differences did not show statistical significance, which indicated the similarity of the data.
Based on the results, under the conditions of the study, it can be appreciated that both sets of images (FS, BS) facilitated the description of the shape of the flowers in the species *Leontopodium alpinum* Cass., under similar conditions of statistical certainty.

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