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Leaves of *Tectaria dissecta* ((G. Forst.) Lellinger) Collected from Three Elevations in Tinago Falls, Iligan City Exhibit Morphological Variation Using Fractal Analysis

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Research Article

Abstract

In this study, the fractal dimension of the leaves of *Tectaria dissecta* was evaluated through fractal analysis to determine any morphological variation that existed in this species in the three elevations in Tinago Falls, Iligan city. Ten samples of *T. dissecta* were collected in each elevation and two to three leaves (fronds) were taken per fern. The leaves were pressed, scanned, processed with the Corel Paint, and binarized images were run with the software using the box-counting method to determine the fractal dimension. FD (fractal index) values of the ferns in the three elevations were compared using the box-and-whisker plot and analyzed using the Kruskal-Wallis ($P<0.05$) to test for the significant difference. Results showed that the average fractal dimension of the fern leaves at high elevation is 1.63, 1.74 in the middle elevation and 1.72 at low elevation. The Kruskal-Wallis test revealed a significant difference in the fractal dimensions of the fern leaves between the high and middle elevation and between the high and low elevation. The ferns in the middle and low elevations have a more complex leaves than in the high elevation as exhibited by higher FD values. The complexity of the fern leaves in the middle and low elevations could be related to the necessity of light penetration through these ferns. The structure of the leaves of the ferns in high elevation assures its needs of light and temperature.

Keywords: Fractal dimension; *Tectaria dissecta*; variation; Box-counting method.

1. Introduction

Morphology or form is usually the first attribute of an organism being studied [1]. Form (like shape) plays a major role in the description of functions on various organisms and is often used to describe differences between species [2,3]. However, most biological shapes seem impossible to describe rigorously or quantitatively because they are too elaborate, irregular, and varying [1]. Many biological objects (leaves, cells, or organelles) display irregular shapes and discontinuous morphogenetic pattern in connection with their functional diversity [4]. A fern leaf is an example in this domain. A quantitative approach to the size and shape of fern leaves has never been formulated [1]. The study about fern leaves showed that the shapes of fronds have fractal properties and fern fronds differ from one species to another [5]. Thus, fractal analysis has received much attention as a number of studies have shown that fractal dimension could be useful for characterizing complex biological structures [6]. Fractal analysis has been applied to describe many aspects connected with the complexity of plant morphology [7]. Fractal dimension is a fractional quantity and is a direct measure of the relative degree of complexity of the object or figure, like the leaves [6,8].

Traditionally, the morphology of objects and organisms has been described based on the Euclidean concept of shape [1]. However, not all patterns in nature are regular (simple) that can be described rigorously using Euclidean geometry. Objects with irregular shapes are called fractals such as coastlines, trees, mountains, and clouds [3,9]. Correct characterization of shapes is important in biology where morphological information about the species of interest can be used in various ways such as for taxonomic classification and studies on morphology and function relationships [10]. The structure of plant vegetation and its geometric elements and objects combined with the total amount of leaf area determine the distribution of light within these plants [5]. The area of leaves is important to individual plants but says nothing about the actual shape of the leaf, which is more likely to influence function, such as the movement of materials into and out of leaves [3].

The present study applies fractal theory to evaluate the fractal dimension of the leaves of *Tectaria dissecta* in order to determine any intraspecific variation that exists in this species in the three different elevations in Tinago Falls, Iligan city. Fractal analysis is used in several researches that characterize plant and soil variability [11,12]. Recent studies have shown that fractal geometry offers succinct and quantifiable descriptions of fern leaves. As mentioned by Campbell [1], fractal geometry treats forms as relationships between parts rather than as areas. There are often constant relationships between parts in fern leaves. Further, Mancuso [10] stated that it is important to define good shape measure that can be effectively applied to leaf shapes, so they can be compared and analyzed by meaningful and objective criteria.

2. Methods

Tinago Falls is a waterfall situated between Barangay Buruun in Iligan City and the Municipality of Linamon, Lanao del Norte. The falls has a total height of 240 ft (73 m). Leaves of *Tectaria dissecta* were collected from three elevations, lower part (25 masl), middle (110 masl) and upper (highest) part (230 masl). Ten ferns were chosen in each elevation and two to three leaves were taken per plant. The leaves were immediately pressed and scanned in the laboratory by an HP scanner with a uniform dpi (600) for image consistency (Figure 1). Then the scanned leaf images were converted into binary images (bitmap) and processed with the Corel Paint. Fractal dimension of binarized images were run with the FracDim software using the box-counting method (BCM). The box-counting method has been shown to be appropriate for estimating fractal dimension of two-dimensional binary images. Binary images are divided into a grid of sub-images, or boxes of fixed length, d, and the number of boxes containing part of an edge, N(d) was counted. N(d) was counted for a range of values of d and then the log[N(d)] versus log(d) was plotted. The most linear portion of the curvature was chosen and linear regression was performed on that segment of the curvature. The box-counting dimension was the negative of the slope of the regression line.

The technique used in this study consists of partitioning the binary images of the ferns in boxes or grids of ascending sizes. For each grid two values were recorded: the number of squared intersected by the image, *N(s)* and the side lengths of the squares, *s*. The regression slope of the straight line between the log transformed value of *N(s)* and 1/*s* was taken as the Fractal index (FD), which ranges from 1 to 2. FD values of the ferns at different elevations were compared using the box-and-whisker plot and then analyzed using the Kruskal-Wallis ($P<0.05$) to test for the significant difference in the FD values between the three elevations. Fractal dimensions could be described as dimensional values $1<D<2$ (since standard shapes have dimensions that are whole numbers; 1 for a line, 2 for a square, etc).

3. Results and Discussion

Figure 2 shows the fractal dimensions of *T. dissecta* leaves in the three elevations in Tinago Falls, Iligan City. The fractal dimensions of *T. dissecta* leaves among the three elevations ranged from 1.21 to 1.85. Results showed that the average fractal dimension of the fern leaves from the high elevation is 1.63 while ferns in the middle elevation are 1.74 and for the ferns at low elevation is 1.72. The Kruskal-Wallis test revealed a very significant difference between the fractal dimensions of the fern leaves in the high elevation and in the middle elevation ($p=0.0004507$) as well as between the high and the low elevations at $p=0.0257$ (Figure 3). However, there was no significant difference observed in the fractal dimensions of the fern leaves between the middle and low elevations this is because the ferns from these two elevations have almost the same average fractal dimension of their leaves.

The obtained results indicated that there is variation in the fractal dimensions of the leaves of *T. dissecta*

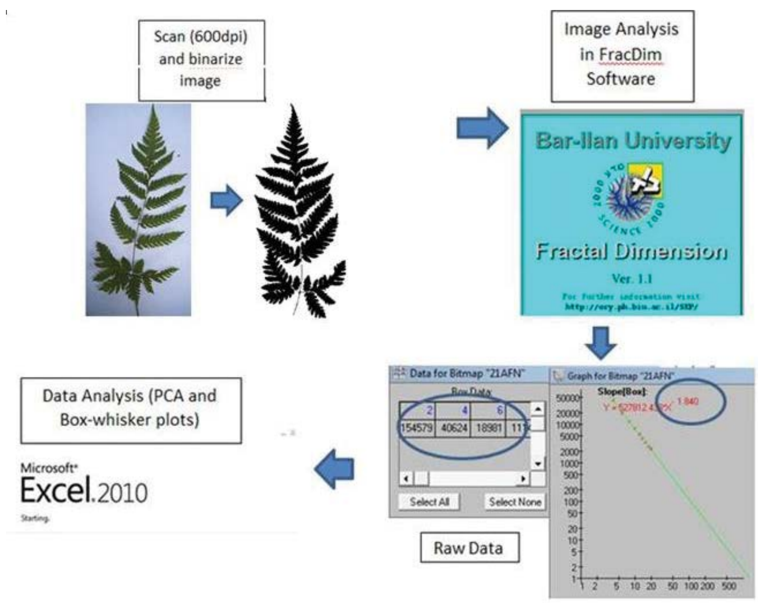

Figure 1. An Illustration of the steps involved in determining the box-counting dimension (BCD) of the binarized *T. dissecta* leaf images in monochrome (black pixels).

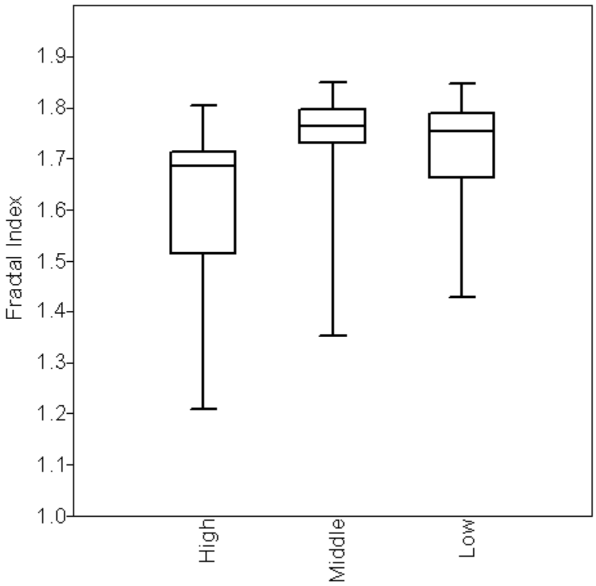

Figure 2. Box-and-whisker plot showing the FD (fractal index) values of *T. dissecta* leaves in the three elevations in Tinago Falls, Iligan City. x axis – Three elevations.

H (chi^2): 12.1
Hc (tie corrected): 12.11
p(same): 0.002348

Mann-Whitney pairwise comparisons, Bonferroni corrected \ uncorrected:

	High	Middle	Low
High		0.0004507	0.0257
Middle	0.001352		0.4924
Low	0.07711	1	

Figure 3. Kruskal-Wallis test showing the significant difference in the FD values of *T. dissecta* leaves among the three elevations in Tinago Falls, Iligan City.

among the three elevations wherein the ferns from the high elevation have smaller leaves compared to the ferns in the middle and low elevations. Also, the leaves of the ferns in the middle and low elevations are more complex than in the high elevation as exhibited by higher FD values and are almost two dimensional (values nearing 2) in structure. As stated by Oancea [5], fractal dimension determines the complexity level of the leaf morphology wherein the higher the FD value the more complex is the plant leaf. The complexity of the leaves of the ferns in the middle and low elevations could be related to the necessity of light penetration through the ferns. Thus, there is a need for the ferns from these two elevations to develop complex and larger leaves in order for them to obtain sufficient amount of light needed for photosynthesis since they are found in shady areas compared to the ferns in the high elevation. This is because less light capture causes lower photosynthetic production in plants [13]. In the other hand, the structure of the leaves of the ferns in the high elevation assures the fern for its need of light as well as temperature. Ferns in the high elevation need not to have larger leaves because they are directly exposed to sunlight. McDonald et al. [14] stated that generally, leaf size declines with increasing altitude, decreasing mean annual rainfall and lower soil fertility. Thus, plants in high elevation tend to have smaller leaves.

Our results is in agreement with the study conducted by Oancea [6] where tomato leaves are more complex and have multiple sinuses than eggplant and pepper leaves because of the need for the tomato plant for efficient light penetration. In another study by Oancea [4], wine grape leaves coming from Europe have a more complex shape than table grape varieties from Asia in order for the solar radiation to penetrate deeper through the sinuses of the wine grape varieties for it to accumulate higher quantities of sugar. Also the leaves of the table grape varieties do not have accentuated lobes because it is from Asia where solar radiation is high and does not necessarily have to reach the leaves that are the closest to the ground.

The size and shape of a leaf influence a range of important physiological processes, including photosynthesis, transpiration, and thermoregulation and varies with a number of environmental factors [15]. According to Givnish [16], effective leaf size (like the width of a leaf or its lobes or leaflets) tends to increase along gradients of increasing rainfall, humidity and/or soil fertility and decrease with increasing irradiance. The study of Yates et al. [15] revealed that species with smaller leaf dimension such as the genera Leucadendron, Leucospermum and Protea are generally associated with hotter and drier environments, a pattern reported previously by Thuiller et al. [17] for Leucadendron. Their data suggested that small leaf dimensions are of principal importance for ensuring convective heat loss when conditions are hot and dry, and air movement is negligible. Thus, it could be assumed that the leaves of the *T. dissecta* in high elevation are smaller because the area is drier and hotter (more exposed to the sun) compared to the two elevations. In contrast, the ferns in the middle and low elevations tend to develop larger leaves because they are found in shady (decreasing irradiance) areas where the soil is moist.

4. Conclusion

The present study emphasizes that fractal analysis is very useful in characterizing the structure of *T. dissecta* leaves in the determination of morphological variation in this fern species. Based on the obtained results, intraspecific variation in terms of the leaf structure (shape and size) of *T. dissecta* existed as exhibited by the significant difference in the fractal dimensions (FD values) of the leaves of this fern in the three elevations in Tinago Falls, Iligan City. Ferns in the middle and low elevations develop complex leaves due to their need for efficient light penetration for greater photosynthetic production within the plant. Thus, they tend to have larger and complex leaves. In the other hand, ferns in the high elevation have smaller leaves partly because of its location where the soil is drier and hotter and more exposed to sunlight, and thus assures the fern's needs for light and temperature. Generally, the structure of a leaf influence various important physiological processes within the plant and varies with a number of environmental factors.

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