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Elliptic Fourier Analysis of Leaf Outline Differences Between and Among Sixteen Species of *Hoya*

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This study illustrates the utility of elliptic Fourier analysis, an outline method of shape analysis, as a tool in describing leaf shape variation in *Hoya*. Leaf contours of 16 species of *Hoya* were compared using this type of outline analysis. Detailed examinations of the leaves were done by performing three separate analyses: one for the overall shape variation using all Fourier descriptors and one each for the symmetric and asymmetric coefficients of the shape descriptors. Leaf shape variation within species was found to be continuous and, because of this, traditional approaches may not be enough to describe the extent of leaf shape diversity within or among taxa. Independent aspects of shape variation were also identified, where more than 96% were related to symmetrical variations that included differences in the length-to-width ratio, location of the widest portion of the leaf, tip shape and width near the leaf base. Five asymmetrical variations were scored which included overall asymmetry (wider on left vs. right), base asymmetry and tip asymmetry. Few leaf shape types were found based on the cluster analysis of the group centroids derived from discriminant analysis and reconstruction of the mean leaf shapes per species, suggesting structural constraints in leaf shape evolution in this group of plants.

INTRODUCTION

Leaf shape varies widely among *Hoya* plants. This feature of the leaf, along with that of the fruits and flowers, are used as characters in the identification of species and varieties. Leaf shape variation within species is generally continuous; however, unlike size, shape is difficult to measure quantitatively. Traditionally, evaluation of the leaf shape of *Hoya* plants involves grading morphological features such as the overall shape of the lamina, apex and base of the blade and wings. This type of evaluation is often subjective and not appropriate for determining continuous shape variation.

Classical descriptions follow a standard set of terms used in describing leaf form and venation to allow objective description of and comparisons among different types of leaves. Common descriptions include linear, oblong, rhombic, cuneate, etc. Unfortunately, these terminologies are not enough to describe the extent of diversity in leaf shapes as one term cannot be used to denote the continuous nature of leaf shape variation. Hence, complex patterns of descriptors are used in defining a range of leaf shape variations, which includes among others modified terminologies such as "broadly elliptic", a hyphenated combination of words such as "obovate-cuneate" and multiple adjectives connected by coordinators and punctuations such as "obovate, lanceolate to oblanceolate". Also, difficulties arise especially when variation between taxa involves only subtle differences in shape, hence, the need to explore other tools, especially quantitative methods, that can best describe shape variations in leaves of this group of plants.

Studies of variations within or among taxa traditionally use an array of morphometric measurements. Traditional morphometric techniques employ a suite of multivariate statistics in analyzing more than one trait in studying patterns of phenotypic variation (Marcus 1990). However, two anatomical structures sometimes show varying amounts of phenotypic integration that, when analyzed separately, would show different patterns of variation (Pigliucci et al. 1991). Usually, morphometric studies focus on variation by means of linear measurements, trying to assess phenotypic divergence among taxa. However, this method is error-prone, thus, alternative methods should be explored to minimize or quantitatively explain the sources of variation. Because of these difficulties, researchers have explored alternative methods of quantifying and analyzing morphological shape. Data that captured the geometry of the morphological structure was of particular interest, and