The Fractal Dimension of Grapevine Leaves as a Tool for Ampelographic Research

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Morphological leaf characters and quantitative measurements of anatomical elements of the leaf, i.e. angles, area, teeth number, petiole length, have been extensively utilised in ampelographic research (OIV-IBPGR-UPOV charts 1983; Galet 1985). However, the origin of the grapevine varieties, their heterogeneity and the frequent cases of homonimy and synonymy, often resulted in doubtful classification. It is thus important to define good shape measures that can be effectively applied to leaf shapes, so they can be compared and analysed by meaningful and objective criteria. One approach that researchers have proposed for describing biological shapes is the fractal based measure of digitally acquired images.

Many pattern of nature are either irregular or fragmented to such an extreme degree that Euclidean geometry cannot describe their form. Thus, fractal geometry based analysis has received increasing attention as a number of studies have shown fractal based measures to be useful for characterising complex biological structures. Fractal scaling is evident in natural objects from the micro-scale to the macro-scale, e.g. the human body contains many structures with fractal characteristics. In fact, it has been found that non-fractal objects were the exception, rather than the rule in many natural systems.

Figure 1: An image of grapevine leaf analysed

Thus, it seemed interesting to verify the possible application of fractal analysis to describe grapevine leaves (*Figure 1*) belonging to different genotypes with the hope to add an objective, clarifying dimension to the excessively convoluted field of ampelography.

The study was carried out with 11 putative Sangiovese-related ecotypes and the registered clone Sangiovese R 10 as a reference (*Table 1*). Samples were collected from the grapevine germplasm collection of the Department of Horticulture of the University of Florence, Italy. At the veraison, 50 fully expanded, healthy leaves, from 15 plants per accession, located between the 7th and 11th shoot node from the apex were selected according to uniformity of appearance, growth habit and exposure.

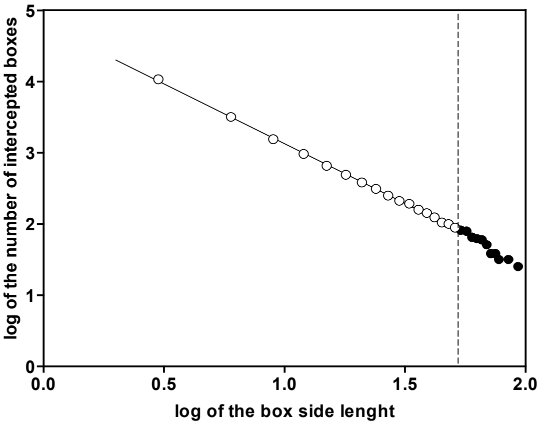

Figure 2: Determination of the fractal dimension

The steps of the box-counting algorithm were as following. The original grayscale image was thresholded to create a binary image, where leaves were represented by black pixels. An edge detection algorithm was applied to the binary image to create an image containing only the edge of the leaf.

The edge image was divided into a grid of square subimages, or "boxes", of fixed length, *d*, and the number of boxes containing part of an edge, N(*d*), was counted. N(*d*) was determined for a range of values of *d*, and then the log[N(*d*)] versus log(*d*) was plotted. The most linear portion of the curve (shown as open circle in *Figure 2*) was chosen and linear regression was performed on that segment of the curve. The box-counting dimension (BCD) was the negative of the slope of the regression line.

The typical technique for determination of the BCD consists in partitioning the image space in boxes of size *d* x *d* and counting the number N(d) of boxes that contain at least one part of the shape to be investigated. Several values of *d* are chosen and the least square fitting of log[N(*d*)] x log(*d*) is used to determine the value of BCD. However, this approximation will suffer the effects caused by spatial quantization as well as the limited fractality of most natural objects (such as grapevine leaves). Therefore the curve log[N(*d*)] x log(*d*) will exhibit two distinct regions (*Figure 2*). The error is minimized calculating D in the region where the curve is most linear. Such guidelines were applied in the present research to the grapevine leaves to obtain their fractal dimensions.

Table 1: Fractal dimension of homogeneous sets of leaves in different Sangiovese-related ecotypes.

Genotype	Mean	S. E.	Minimum	Maximum
Prugnolo gentile	1.301	0.001	1.283	1.310
Brunellone	1.294	0.001	1.271	1.316
Brunelletto	1.230	0.004	1.202	1.274
Prugnolo acerbo	1.457	0.003	1.415	1.472
Prugnolo dolce	1.448	0.001	1.426	1.462
Prugnolo medio	1.468	0.001	1.444	1.482
Casentino	1.204	0.008	1.136	1.294
Chiantino	1.240	0.003	1.216	1.298
Morellino	1.278	0.001	1.262	1.315
Morellino di Scansano	1.246	0.004	1.225	1.302
Piccolo precoce	1.499	0.002	1.471	1.512
Sangiovese R 10	1.372	0.001	1.353	1.389

The fractal dimensions of a homogeneous sample of leaves from different *Sangiovese*-related genotypes are listed in Table 1. The mean values of BCD ranged from 1.204 for *Casentino* to 1.499 for *Piccolo precoce*, showing a rather ample interval.

In spite of plant variability, the fractal dimension can be found quite accurately with a small sample size. The average standard error of D for 12 genotypes shown in Table 1, for example, was only 0.19 % (n = 50), that is much less than the standard error that occurs using the traditional ampelographic parameters.

A fundamental question on the applicability of fractal analysis to vine leaves is if vine leaves are genuine self-similar objects. Results presented here show that leaves are not truly fractal because they do not show the highly hierarchical structure characteristic of artificial fractal object. Nevertheless, the BCD gives an effective dimension that can be used to measure the complexity of highly complex structures such as vine leaves. Complex objects may show a power-law property over a limited range of scales and this property may be captured using fractal techniques. Similar discussions were met in the application of fractal analysis to other not truly fractal objects as the human trabecular bone or the neurons. Consequently, this study rather than proposing that vine leaves are fractal, emphasizes the usefulness of fractal analysis in ampelography.

Literature

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