Student Research paper submitted for 1983 U. P. Hedrick Award:

Numerical Methods for Classifying Avocado Cultivars

ROBERT J. LEBOWITZ[1]

There are three horticultural races of avocado (*Persea americana* Mill.)—Mexican, Guatemalan, and West Indian. These races have several commercially important distinctions such as climatic adaptation, annual vs. alternate bearing tendencies, and fruit ripening season. To differentiate between these races, Popenoe (1920) developed a taxonomic key based on a limited number of leaf and fruit characteristics (see Table 1). Since that time, additional racial descriptors have been suggested by Hodgson (1950), Ruehle (1963), and Bergh (1975).

Because many of the characteristics used in Popenoe's key (1920) can be expressed quantitatively, it is possbile to derive racial classifications of avocado cultivars by numerical methods. The first such avocado "numerical taxonomy" was made by Anderson (1969). He classified a Mexican and Guatemalan racial hybrid population on the basis of a few leaf characters using a pictorialized scatter diagram technique. An example of a pictorialized scatter diagram is seen in Figure 1. Plotting cultivars according to their average internode length and fruit stem length (represented by the X and Y axes respectively) indicates certain similarities amongst some Mexican and Guatemalan hybrids.

Rhodes, et al. (1971) have demonstrated the use of multivariate statistical techniques for determining an avocado cultivar's racial classification. They used principle component analysis to classify 38 avocado cultivars using quantitative data for 67 morphological characters. Principle component analysis produces scatter diagrams which represent the projections of cultivars into one or more axes like Anderson's pictorialized method (1969), however principle component analysis differs in the sense that each axis carries quantitative aspects of more than one character. The diagram in Figure 2 illustrates the spatial relationships of the 38 avocado cultivars based on their morphological characteristics. The analysis placed the Mexican and Mexican-Guatemalan and Guatemalan-Mexican hybrid cul-

Table 1. Popenoe's key (1920) to the avocado races.

A.	Leaves anise scented: skin of fruit thin and soft ..... Mexican Race
AA.	Leaves not anise scented: skin of fruit thick
B.	Surface of fruit usually smooth: skin leathery, usually not more than 1/16 inch thick; seed coats frequently distinct, the outer one adhering to wall of seed cavity; cotyledons often rough ..... West Indian Race
BB.	Surface of fruit usually rough or warty: skin brittle, granular, 1/16 - 3/16 inch thick; seed coats adhering closely to the nearly smooth cotyledons ..... Guatemalan Race

[1]Dept. of Agronomy, University of Illinois, Urbana-Champaign, Illinois 61801.

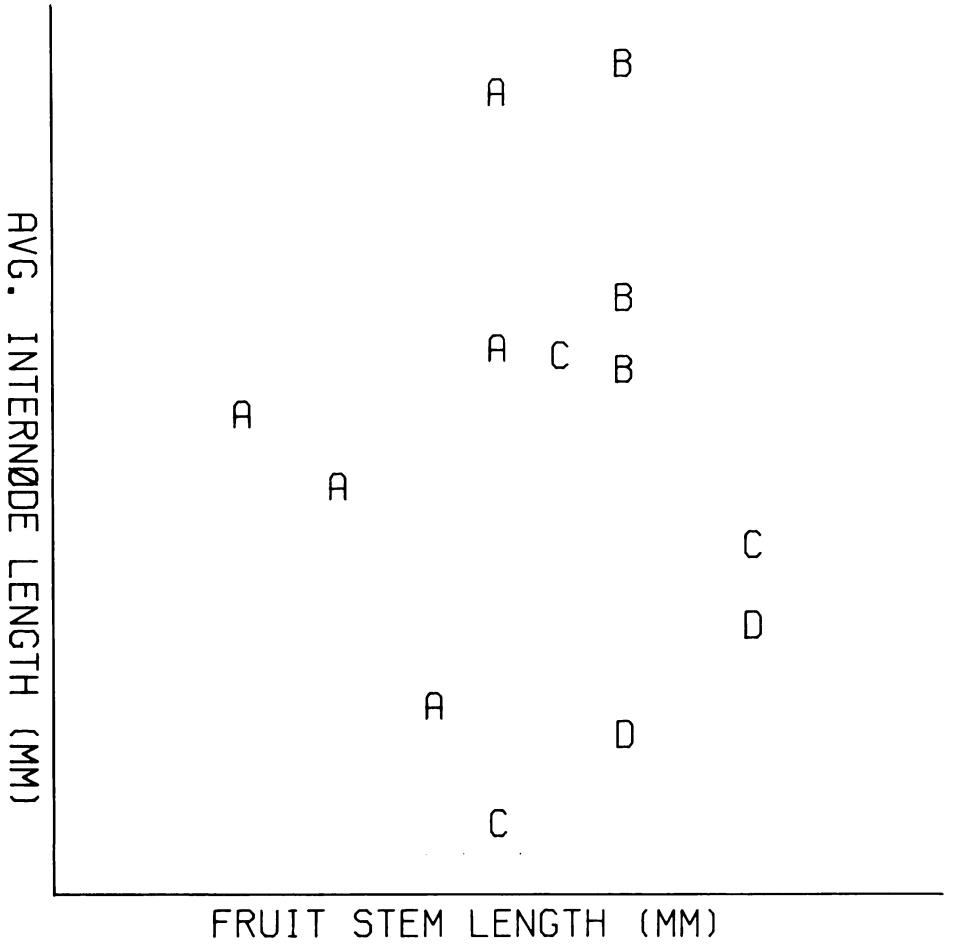

Fig. 1. Pictorialized scatter diagram illustrating racial differences of the Guatemalan and Mexican races of the basis of two metric characteristics; fruit stem length and average internode length. Key (The predominant race is listed first): A = Guatemalan, B = Guatemalan-Mexican, C = Mexican-Guatemalan, D = Mexican.

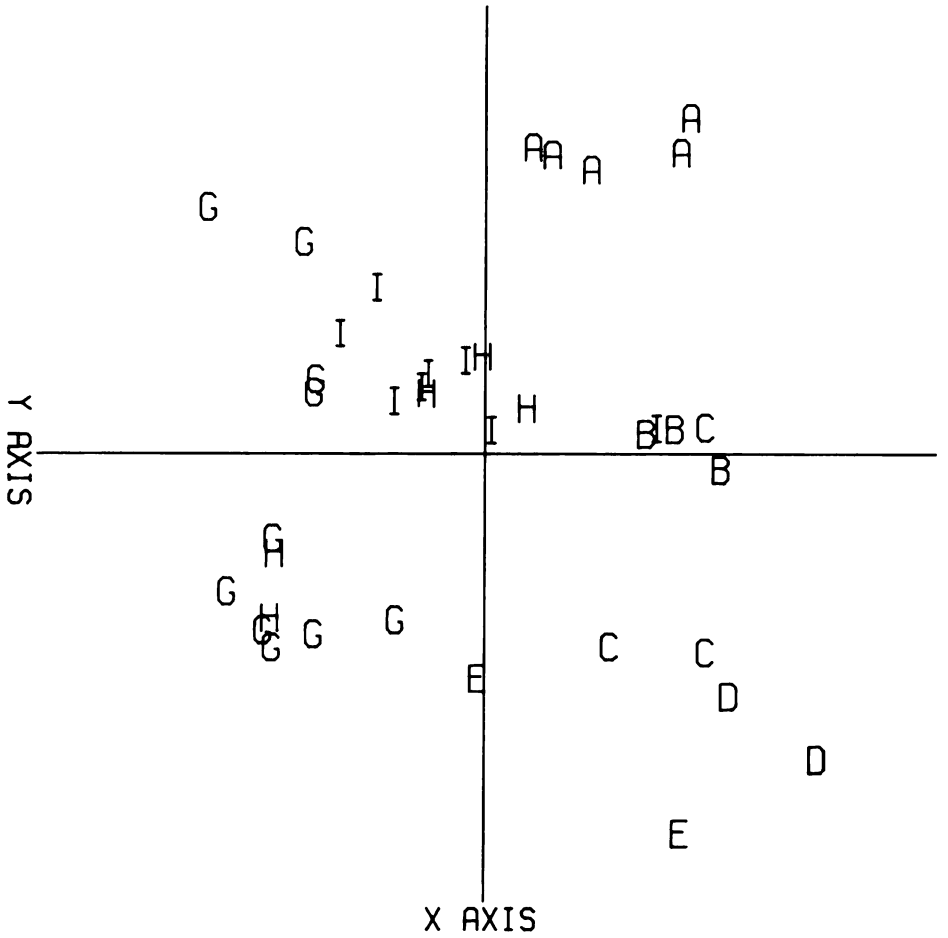

Fig. 2. Scatter diagram illustrating the projection of 38 avocado cultivars unto the first two principle component axes. These axes account for a majority of the phenotypic variations observed within this limited germplasm collection. Key (the predominant race is listed first): A = Guatemalan, B = Guatemalan-Mexican, C = Mexican-Guatemalan, D = Mexican, E = Mexican-West Indian, F = West Indian-Mexican, G = West Indian, H = West Indian-Guatemalan, I = Guatemalan-West Indian.

Table 2. Names and presumed racial types of the cultivars used in this study. The predominant racial type is listed first. (Key: G = Guatemalan, M = Mexican, W = West Indian).

Code	Cultivar	Parentage	Presumed Race
OTU 1	Ajax	Open pollinated seedling	G x W
OTU 2	Areu		W
OTU 3	Areu seedling		W
OTU 4	Avila	Chance seedling	W
OTU 5	Black Prince		W x G
OTU 6	Blake seedling	Chance seedling	G x W
OTU 7	Booth 5	Chance seedling	G x W
OTU 8	Booth 7	Open pollinated seedling	G x W
OTU 9	Booth 8	Open pollinated seedling	G x W
OTU 10	Brogdon		M x W
OTU 11	Catalina		W
OTU 12	Chandler		W x G
OTU 13	Courtright		M x W
OTU 14	Ettinger		M x G
OTU 15	Harris	Open pollinated seedling of 'Wagner' cultivar	G
OTU 16	Hass		G
OTU 17	Hickson		G x W
OTU 18	Lawhon		W
OTU 19	Lounsbury		G
OTU 20	Lula	Open pollinated seedling of 'Taft' cultivar	G x W
OTU 21	Major		G x W
OTU 22	Mexican seedling		M
OTU 23	Monroe		G x W
OTU 24	NT-4		M x G
OTU 25	Nadir	Possibly hybridized with a Guatemalan type	W x G
OTU 26	Nezahualcoyotl		M x G
OTU 27	Peterson		W
OTU 28	Pollock		W
OTU 29	Reinecke 1		G x M
OTU 30	Reinecke 12		G x M
OTU 31	Ruehle	Open pollinated seedling of 'Waldin' cultivar	W
OTU 32	Schaff		W x G
OTU 33	Tappen		W x G
OTU 34	Taylor		G
OTU 35	Tonnage	Open pollinated seedling of 'Taylor' cultivar	G
OTU 36	Trapp		W
OTU 37	Waldin		W
OTU 38	Winter Mexican		G x M

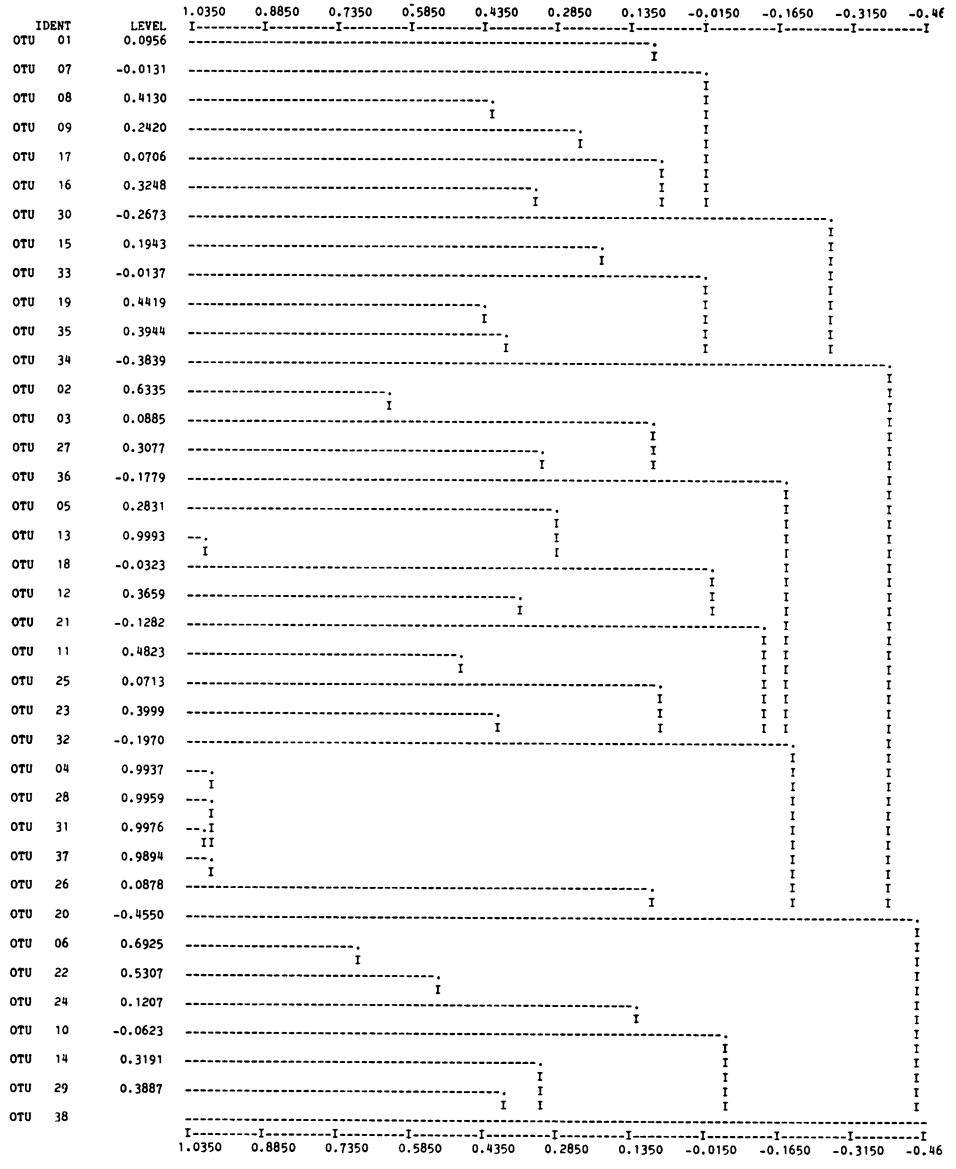

Fig. 3. Dendrogram illustrating the systematic relationships between 38 avocado cultivars. The three clusters found at level −0.3839 represent the three avocado races (see text).

tivars in the lower right quadrant. The Guatemalan cultivars and the Guatemalan-Mexican and Guatemalan-West Indian hybrid cultivars appear in the upper right quadrant. The West Indian and West Indian-Guatemalan hybrids are scattered throughout most of the lefthand portion of the diagram. This example serves to demonstrate principle component analysis' efficacy in distinguishing avocado races.

Rhodes, et al. (1971) also used cluster analysis to racially classify avocado cultivars. Cluster analysis provides a discrete representation of the systematic relationships within a given set of cultivars. Assuming that the relationships amongst the cultivars has a hierarchical structure, the authors used an average-link hierarchical clustering scheme to classify the same 38 avocado cultivars earlier examined by principle component analysis. Relationships or similarities between pairs of avocado cultivars were expressed quantitatively as correlation coefficients. The hierarchical clustering scheme then takes individual or "mutually exclusive" cultivars or clusters (groups) and forms larger clusters depending on their similarity. The process continues reiteratively until only one cluster remains. The hierarchy of clusters formed during cluster analysis is usually illustrated as a tree-like structure called a dendrogram. Figure 3 contains a dendrogram representing a hierarchical classification of the 38 avocado cultivars listed in Table 2. The three clusters formed at level −0.3839 reflect the predominant racial classifications of the cultivars. From top to bottom, the first 12 cultivars in Figure 3 (OTU 01 - OTU 34) represent the predominantly Guatemalan cultivars, the next 13 cultivars (OTU 02 - OTU 20) represent the predominantly West Indian cultivars, and the last 13 cultivars (OTU 06 - OTU 38) represent the predominantly Mexican cultivars.

All of the above numerical methods can be used to racially classify avocado cultivars. The same methods also illustrate the phenotypic (and presumably genetic) diversity that exists within the avocado germplasm complex. This suggests that numerical classification methods like these could be used by geneticists to select diverse breeding stocks for use in avocado and other fruit breeding programs.

Literature Cited

Anderson, E. 1969. Plants, man and life. Univ. California Press.

Bergh, B. O. 1975. Avocados. In: Advances in fruit breeding. Janick, J. and J. N. Moore (eds.). Purdue Univ. Press.

Hodgson, R. W. 1950. The avocado—a gift from the middle Americas. Econ. Bot. 4:253-293.

Popenoe, W. 1920. Manual of tropical and subtropical fruits. MacMillan, New York.

Popenoe, W. 1936. Origin of the cultivated races of avocado. Calif. Avocado Assoc. Yearbook 1935:184-194.

Popenoe, W. 1969. The value of systematic pomology in tropical fruit culture. Proc. Fla. State Hort. Soc. 82:309-313.

Rhodes, A. M., S. E. Malo. C. W. Campbell. and S. G. Carmer. 1971. A numerical taxonomic study of the avocado (*Persea americana* Mill.). J. Amer. Soc. Hort. Sci. 96:391-395.

Ruehle, G. D. 1963. The Florida avocado industry. Fla. Agr. Expt. Sta. Bull. No. 602.