Selection based on distances from ideotype

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ABSTRACT

Two selection methods based on distance from ideotype using selection index and principal components are proposed. They took into consideration the existence of an optimum range for each trait, the difference in scale of the measurements and the relative importance of the traits. The index was also based on mean Euclidean distance. Analysis performed by considering four eggplant traits and a 35,3% selection pressure showed that the two selection methods presented the same predicted genetic gains.

KEY WORDS: Eggplant, euclidean distance, principal components, selection index.

INTRODUCTION

Tandem selection and selection based either on independent culling levels or on an index are used for the selection of superior genotypes by considering several traits. Hazel and Lush (1942) and Young (1961) compared the relative efficiency of these methods in terms of genetic gain and concluded that, theoretically, selection based on an index was never less efficient than the other two methods.

Selection indices combine genetic and economic information in a regression equation for the prediction of the value of a genotype. In addition, they combine the information for many traits into a single value (Bridgwater et al., 1983). Despite its relevance, selection index theory presents certain limitations both of a practical and a methodological order. The major limitations described by Lin (1978) are: 1) imprecise estimates of variances and covariances, 2) possibility of changes occurring in the parameters with selection, and 3) difficulty in establishing the relative importance of the traits. However, these complicating factors apply to the general problem of multitrait selection and do not necessarily weigh more heavily against the selection index than against other approaches to that problem (Martin et al., 1982).

Selection based on an index may tend to choose genotypes that express the highest phenotypic values for the traits targeted to obtain positive genetic gains and the lowest phenotypic values for traits targeted to obtain negative genetic gains. However, in some cases, the phenotypic value considered optimum is in the range between the maximum and minimum values expressed by the genotypes. An optimum range can be established for these traits, outside of which the product undergoes devaluation on the consumer market or is curtailed in production. In eggplants, for example, fruit diameter and length are traits included in the first case and plant height is included in the second case. In selecting for height, very tall or very short plants are considered undesirable because of harvesting difficulties. The phenotypic values used to obtain a selection index are located outside the optimum range should therefore be depreciated. Depreciation refers to the increase in the distance of the phenotypic value from the value considered optimum.

Harding et al. (1991) elaborated an index denoted weighted Euclidean distance index to classify phenotypes in relation to an optimum phenotype, which may be intermediate in value. Tourjee et al. (1995) applied this index to select genotypes expressing phenotypic values that minimize the mean distance in relation to an optimum value for flower colour in the Davis population of Gerbera. Although genotype scores are obtained by calculating the difference between the reference point and the observation for each trait, this index does not take into consideration the difference in scale of the measurements or the existence of an optimum range for each trait.

The purpose of this report was to present two selection methods based on distance from ideotype: a) use of the selection index, and b) analysis of graphic dispersion on axes established by principal components. The index was constructed and the study by principal components was conducted taking into

consideration the existence of an optimum range for each trait, the effects of the measuring scale and the relative importance of the traits. The index established was also based on mean Euclidean distance. As illustration, selections based on distance from an eggplant ideotype were done.

MATERIAL AND METHODS

We analyzed the data obtained in a trial with 17 eggplant (*Solanum melongena* L.) accessions from the Vegetable Germplasm Bank of the Department of Genetics, ESALQ/USP, carried out under field conditions in the municipality of Piracicaba, SP, Brazil.

The experimental design was a randomized complete block with three replications. Each plot consisted of a single row with eight plants spaced 0.5 m apart. Row spacing was 1.0 m. The four central plants represented the useful plot.

The evaluated traits were: 1) mean length of commercial fruits, in cm (FL), 2) mean diameter of commercial fruits, in cm (FD), 3) mean weight of commercial fruits, in grams (FW) and 4) total weight of commercial fruits/plant, in grams (FTW). The data was obtained from unripe fruits.

Limits, range of phenotypic values and index calculation

Lower (LI_j) and upper (LS_j) limits of the optimum range were established for each trait (Table 1). Egg plant fruits are commercialized unripe, with shiny purple coloring. In this state, the limits set out for commercialization (limits of the optimum range indicated on Table 1) referent to FL, FD and FW ensure tender fruits with soft and pale seeds and pulp, considered ideal for human consumption (Filgueira, 1982). The optimum phenotypic value (VO_j) for these traits corresponded to the mean point of the optimum range. With respect to FTW, VO_j was equal to the highest mean phenotypic value expressed by the accessions evaluated. In this case we considered $VO_j = LI_j = LS_j$.

The accessions were submitted to selection by means of an index expressed by the mean Euclidean distance from ideotype. This index was constructed as described below.

Let us consider X_{ij} to be the mean phenotypic value of the ith accession referring to the jth trait, Y_{ij} to be the mean transformed phenotypic value, and C_j the constant related to depreciation. Let us also

consider that:

if $LI_j \leq X_{ij} \leq LS_j$ then $Y_{ij} = X_{ij}$

if $X_{ij} < LI_j$ then $Y_{ij} = X_{ij} + VO_j - LI_j - C_j$

if $X_{ij} > LS_j$ then $Y_{ij} = X_{ij} + VO_j - LS_j + C_j$

In this trial, we considered $C_j = LS_j - LI_j$ (Table 1). This C_j value guarantees that any X_{ij} value within the optimum range will result in a Y_{ij} value of a magnitude closer to VO_j than the value obtained for X_{ij} outside this range. The transformation of X_{ij} is performed in order to depreciate the mean phenotypic values outside the optimum range.

Let us also consider y_{ij} to be the ijth transformed mean phenotypic value standardized and weighted according to the square root of the relative importance of the jth trait, $S(Y_j)$ the standard deviation of the mean transformed phenotypic values of the jth trait including that of the ideotype, and vo_j the optimum phenotypic value standardized and weighted according to the square root of the relative importance of the jth trait. Thus, we have:

$$y_{ij} = \sqrt{a_j}\,\frac{Y_{ij}}{S(Y_j)}\,;\ vo_j = \sqrt{a_j}\,\frac{VO_j}{S(Y_j)}\ ;\ \text{and}$$

$$IDI = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(y_{ij} - vo_j)^2}$$

where IDI is the index based on the distance from ideotype, n is the number of traits included in the index, and a_j is the relative importance for the jth trait. The ideotype was defined as the accession, not necessarily evaluated, presenting a mean phenotypic value for each trait equal to the respective VO_j.

The coefficients of genotypic variation (CV_g) of traits were used as economic weights to calculate the IDI (Cruz, 1990, Carvalho et al., 1999). As transformation was made at the mean plot level, these coefficients were obtained based on the non-transformed data. For the calculation of genetic gain according to Baker (1986), we selected the accessions evaluated that presented the lowest scores for the calculated index. The selection pressure used was 35,3%.

The accessions were also submitted to selection by means of graphic analysis considering their positions in relation to the ideotype along the axes established

by the principal components as described by Hotteling (1933). The original variables used to obtain these components were the mean transformed phenotypic values standardized and weighted according to the square root of the relative importance of the respective trait.

Genetic gain was calculated by selecting the accessions evaluated that presented the lowest graphic dispersions in relation to the ideotype. To facilitate the visualization of the position of the accessions in relation to the ideotype, circles were drawn around the graphic point referring to the ideotype. The relative importance of the traits and the selection percentage were the same as used for IDI. The analyses of this assay were carried out using the GENES computation software (Cruz, 1997).

Transformation of the phenotypic values

To carry out the two stage transformation of phenotypic values proposed before selection, it is necessary to define the optimum range (upper and lower limit), the optimum phenotypic value and the value of the constant related to depreciation, in addition to the relative importance of the traits.

In this study, the optimum range for FL, FD and FW was established based on the commercial standard of egg plant fruits. This standard refers to a set of visual traits that allow the identification of the product to be commercialized and ensure, to a certain extent, its nutritional quality. The expression of phenotypic values for these traits, within the intervals presented in Table 1, indicates that the fruit is unripe, specially when the coloring and shine are also considered (Filgueira, 1982). Consequently, the seeds of this fruit are in formation and have great nutritional value, mainly in terms of mineral salts and vitamins.

After depreciation (first stage of transformation), the distance between VO_j and any Y_{ij} value originated

Table 1. Magnitudes of the optimum phenotypic value (VO_j), of the lower (LI_j) and upper (LS_j) limits, and of the constant related to depreciation (C_j) for the four traits evaluated [1/].

	FL	FD	FW	FTW
VO_j	14.5	7.0	245.0	3103.316
LI_j	12.0	6.0	220.0	3103.316
LS_j	17.0	8.0	270.0	3103.316
C_j	5.0	2.0	50.0	0.000

[1/] FL: mean length of commercial fruits; FD: mean diameter of commercial fruits; FW: mean weight of comercial fruits and FTW: total weight of commercial fruits/plant.

from an X_{ij} outside the optimum range is greater than the distance obtained between VO_j and Y_{ij} any value originated from an X_{ij} within this range (Table 2). Thus, besides LI_j and LS_j, VO_j must be determined in such a way that there will be coherence in the transformation. Consider, for example, a VO_j value much closer to LI_j than to LS_j. Before transformation there are values lower than LI_j whose distance in relation to VO_j is lower than the distance between VO_j and LS_j. However, the two selection methods reported show a tendency to choose an accession that will express LS_j value instead of another accession that will express some of these values lower than LI_j. If coherence exists in this selection, this means that the parameters were properly established. The optimum value for FL, FD and FW was the mean point of the optimum interval, as there is no reason to establish VO_j closer to one limit than another. This criteria makes VO_j easier to find and, also, the phenomenon described above does not occur.

For FTW, the equality $VO_j = LI_j = LS_j$ was assumed. However, it is not necessary to consider this equality for all traits whose VO_j is the highest or the lowest mean phenotypic value. In cocoa (*Theobroma cacao* L.), for example, seed size and quality are associated. Small seeds generally have undesirable qualities such as low fat and high husk content (Glendinning, 1963). Thus, the chocolate industry established a mean dry seed weight not lower than 1g as minimum required limit for a good quality product (Wood, 1979). In this context, the parameters for this trait can be defined as $LI_j = 1$ gram and $LS_j = VO_j =$ highest mean phenotypic value. It should be pointed out that the equality $VO_j = LI_j = LS_j$ can also be established for traits whose VO_j is in the range between the maximum and minimum values expressed by the genotypes, when the breeder does not intend to depreciate the phenotypic values. Selection for optimum values has been discussed by Brascamp (1984) and Baker (1986).

The following expression $C_j = LS_j - LI_j$ was used for the calculation of Y_{ij} for all traits. Other C_j expressions specific for each trait could have been used. However, the constant related to depreciation cannot have a value of less than $VO_j - LI_j$ or less than $LS_j - VO_j$ since, if this were the case, X_{ij} outside the optimum range may result in a Y_{ij} value of magnitude closer to the ideotype than the value obtained for X_{ij} within this range. For depreciation of all the values outside the optimum range to occur, C_j should have a value higher than $VO_j - LI_j$ and $LS_j - VO_j$. When the values of VO_j, LI_j, and LS_j are equal to the highest mean phenotypic value expressed by the accessions, as established for FTW, we should consider $C_j = 0$. In

this case there is no depreciation of any mean phenotypic value.

When depreciation occurs, it will be of the same magnitude for all X_{ij} values outside the optimum range only when VO_j is the midpoint between LI_j and LS_j. An important aspect to be pointed out is that, in both methods previously reported, the accessions which express these X_{ij} values are not eliminated as observed in the method of independent culling levels. As the C_j value increases there will be a tendency to select the accessions that show mean phenotypic values within the optimum range for the jth trait. For example, when the breeder wants the value assumed by an accession for trait j to be necessarily within the optimum range, a high C_j value can be used. In this case, the use of the selection index or principal component will select the accessions as done by the method of independent culling levels only with respect to the jth trait.

The depreciation of the observed phenotypes, depending on the values of constants used in this process, could introduce discontinuities into the data. In effect a unimodal distribution of mean phenotypic values could be made bimodal or trimodal. In other words, if the data were normally distributed before depreciation, they are unlikely to be so afterwards. This can lead to an increase in $S(Y_j)$ and raises the question of the validity of its use for data standardization (second stage of data transformation). When the C_j value is low, the increase in $S(Y_j)$ may have irrelevant magnitude, and consequently, will not greatly influence the standardization procedure. Larger standard deviations will be obtained when the value of the depreciation constant is increased. If C_j and the optimum interval are large, few mean phenotypic values will be depreciated. To reduce possible adverse effects of the data discontinuity on the standardization, these values can be left out in the $S(Y_j)$ calculation. When C_j is high and the optimum interval has a lesser magnitude, many X_{ij} values can be depreciated and these should be considered when obtaining the deviation. The high deviation obtained from this depreciation may reduce the weight of the respective trait in the IDI and in the principal components method. However, this does not invalidate the use of these methods.

As previously mentioned, one of the greatest difficulties in multitrait selection is the establishment of the relative importance of the traits, as this is not always obvious to the breeder (Godshalk and Timothy, 1988). Several methods have been proposed to obtain such rank (Dickerson et al., 1954; Allaire and Henderson, 1966; Van Vleck, 1974; Andrus and McGilliard, 1975; Cruz, 1990). In this study, the coefficients of genetic variation were considered as relative importance of the traits (Cruz, 1990). According to the author, the CV_g is directly proportional to the available genetic variance, maintains the proportionality between the traits and is dimensionless. The weighting of the phenotypic values permits the trait of highest relative importance to increase its contribution to the score of index or the genetic divergence (principal components) of the accessions in relation to the ideotype.

RESULTS AND DISCUSSION

The transformed phenotypic values were submitted to selection. Selection of accessions expressing phenotypic values that minimize the mean distance in relation to an optimum value was performed by means of a index and of analysis of graphic dispersion on axes established according to principal component analysis.

In IDI, the accessions evaluated that presented the lowest scores for the calculated index were used for the calculation of genetic gain since, the lower the index score for an accession, the closer it is to the ideotype. When the FL, FD, FW and FTW traits were included in the index with respective relative importance (20.210:26.117:55.475:36.519) according to their respective genotypic coefficient of variation, accessions 1, 3, 16, 14, 5 and 6 presented the lowest scores (Table 2). The genetic gains predicted from selection are listed in Table 3. It should be pointed out that the choice of accessions closer to the ideotype does not necessarily imply greater predicted genetic gains in absolute values. These gains are obtained when the highest or lowest mean phenotypic values are selected. In this index, an accession is selected on the basis of its distance from the ideotype, which may be intermediate in the values. Thus, the mean value for the selected accessions tends to be close to VO_j.

The viability of the principal component analysis in studies on genetic divergence depends on the possibility of reducing the set of original variables to a few components, i.e., having a good approximation of the distance between genotypes in the n-dimensional space, in a two- or three-dimensional space (Cruz and Regazzi, 1994). The estimates of the variances associated with the principal components and of the weighting coefficients of the original

Table 2. Magnitudes of the non-transformed (X_{ij}) and transformed (Y_{ij}) mean phenotypic value and of the index score for the 17 accessions evaluated and for the ideotype in terms of four eggplant traits [1]

Accessions	FL		FD		FW		FTW		Index
	X_{ij}	Y_{ij}	X_{ij}	Y_{ij}	X_{ij}	Y_{ij}	X_{ij}	Y_{ij}	score
1	15.633	15.633	6.736	6.736	227.420	227.420	3103.316	3103.316	1.002
2	10.540	8.040	3.650	2.650	49.776	24.776	1638.286	1638.286	12.322
3	15.800	15.800	6.386	6.386	191.750	166.750	2575.120	2575.120	3.866
4	12.263	12.263	9.040	10.040	328.380	353.380	1672.916	1672.916	8.401
5	13.116	13.116	5.473	4.473	122.133	97.133	2350.123	2350.123	7.178
6	10.436	7.936	6.520	6.520	170.676	145.676	1930.250	1930.250	7.455
7	11.760	9.260	5.350	4.350	112.940	87.940	1192.366	1192.366	11.111
8	9.690	7.190	6.180	6.180	125.370	100.370	1367.916	1367.916	10.298
9	11.346	8.846	4.716	3.716	91.430	66.430	657.500	657.500	13.583
10	16.933	16.933	4.916	3.916	163.630	138.630	1470.000	1470.000	9.074
11	12.416	12.416	4.280	3.280	72.150	47.150	639.956	639.956	13.813
12	9.773	7.273	3.680	2.680	44.000	19.000	1787.870	1787.870	12.291
13	10.033	7.533	3.666	2.666	56.923	31.923	1683.456	1683.456	12.138
14	16.043	16.043	6.906	6.906	257.600	257.600	1820.416	1820.416	5.649
15	15.333	15.333	7.010	7.010	249.486	249.486	1150.583	1150.583	8.465
16	14.853	14.853	7.420	7.420	255.670	255.670	2052.500	2052.500	4.598
17	9.283	6.783	5.253	4.253	91.083	66.083	1411.110	1411.110	11.464
ideotype	14.500	14.500	7.000	7.000	245.00	245.000	3103.316	3103.316	-

[1] FL: mean length of commercial fruits; FD: mean diameter of commercial fruits; FW: mean weight of comercial fruits and FTW: total weight of commercial fruits/plant.

Table 3. Means for the selected accessions ($\overline{X}_S$) and for the population ($\overline{X}_0$), heritability (h^2) and predicted genetic gain (GS), on the basis of selection on IDI and principal components, for four traits evaluated in eggplants [1]

Trait	$\overline{X}_S$	$\overline{X}_0$	h^2	GS	GS%
FL	14.314	12.662	96.814	1.599	12.63
FD	6.574	5.717	98.751	0.846	14.80
FW	204.208	153.554	98.174	49.729	32.39
FTW	2305.287	1676.684	94.176	591.993	35.31

[1] FL: mean length of commercial fruits; FD: mean diameter of commercial fruits; FW: mean weight of comercial fruits and FTW: total weight of commercial fruits/plant.

variables are listed in Table 4. According to Cruz and Regazzi (1994), in order to have a negligible degree of distortion in the transposition from the n-dimensional to the two- or three-dimensional space, the two or three components utilized must explain at least 80% of total variation. Table 4 shows that the first two components explained 90.85% of total variation. Thus, the results demonstrated that the distortion of the coordinates of each accession in the dispersion graph whose axes are the first two principal components is considered acceptable and that the inferences in the study of genetic divergence are satisfactory. The merit of the principal components in the selection process has been discussed by Hayes and Hill (1980) and Godshalk and Timothy (1988).

Fig.1 presents the graphic dispersion of the ideotype and of 17 accessions evaluated in relation to the first two principal components considering the FL, FD, FW and FTW traits. To facilitate the visualization of the position of the accessions in relation to the ideotype, two circles were drawn around the graphic point referring to the ideotype. It can be seen that the six accessions selected on the basis of IDI scores were those that presented the lowest graphic dispersion in relation to the ideotype. Whenever the accession number is large, it becomes difficult to visualize their position in relation to the ideotype. The Euclidian distance of the accession from the ideotype can be calculated in the dispersion graph in these cases.

The comparison of the two selection methods indicated that the IDI has advantage over the principal component analysis because it reduces the set of traits to one single trait (the index). Furthermore, the viability of this last analysis is associated with the

Table 4. Estimated variances (eigenvalues, λ_j) associated with the principal components (CP$_j$), and of the weighting coefficients (eigenvector elements) of the original variables.

CP$_j$	Eigenvalue		Weighting coefficient[1/]			
	λ_j	accumulated %	FL	FD	FW	FTW
CP$_1$	98.413	71.14	0.3302	0.4735	0.7290	0.3679
CP$_2$	27.263	19.71	0.0241	-0.2366	-0.3201	0.9171
CP$_3$	11.696	8.45	0.8954	-0.4143	-0.0601	-0.1514
CP$_4$	0.949	0.68	0.2976	0.7404	-0.6021	-0.0270

[1/] FL: mean length of commercial fruits; FD: mean diameter of commercial fruits; FW: mean weight of comercial fruits and FTW: total weight of commercial fruits/plant.

fact that it keeps, in a few components, the maximum amount of information in terms of total variation in the initial data. The disadvantage of the use of the standardized mean Euclidian distance in selection is that it does not take into consideration the correlation among the available traits. When there is correlation, the dispersion graph axles are oblique and the estimation of this distance may become inadequate (Mahalanobis, 1936). On the other hand, the principle components are not correlated. In spite of non-zero correlations among the evaluated traits in this study, both methods presented the same predicted genetic gain for the traits when a 35.3% selection pressure was applied (Table 3).
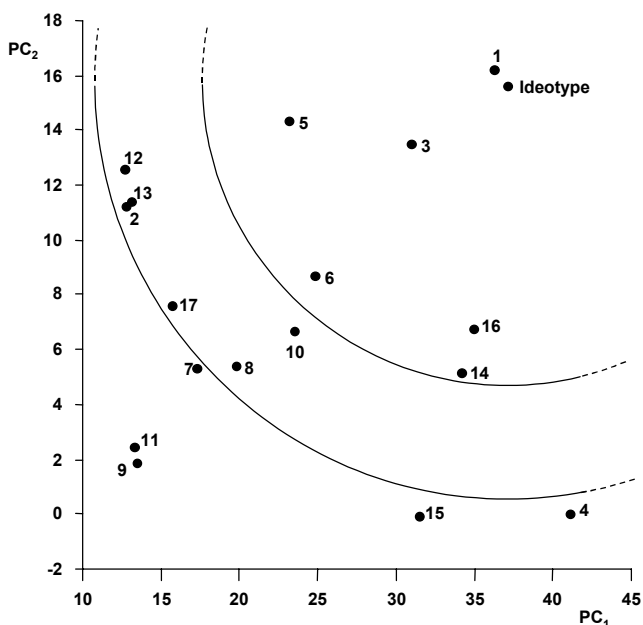

Figure 1. Graphic dispersion of the scores for the ideotype and for 17 accessions evaluated in relation to the axes representative of the first two principal components (CP$_1$ and CP$_2$) considering five traits evaluated in eggplants.

RESUMO

Seleção com base na distância em relação ao ideótipo

Dois métodos de seleção com base na distância em relação ao ideótipo, utilizando-se índice de seleção e componentes principais, foram propostos. Eles levaram em consideração a existência de um intervalo ótimo para cada caráter, a mudança de escala de medições e a importância relativa dos caracteres. O índice estabelecido foi fundamentado, também, na distância Euclidiana média. A análise, considerando quatro caracteres de berinjela e 35% como percentagem de seleção, evidenciou que as duas estratégias de seleção apresentaram os mesmos ganhos genéticos preditos.

REFERENCES

Allaire, F.R. and Henderson, C.R. 1966. Selection practiced among dairy cows. II. Total production over a sequence of lactation. Journal Dairy Science. 49:1435-1440.

Andrus, D.F. and McGilliard, L.D. 1975. Selection of dairy cattle for overall excellence. Journal Dairy Science. 58:1876-1879.

Baker, R.J. 1986. Selection indices in plant breeding. CRC Press, Florida.

Brascamp, E.W. 1984. Selection indices with constraints. Animal breeding abstracts. 52:645-654.

Bridgwater, F.E.; Talbert, J.T. and Jahromi, S. 1983.

Index selection for increased dry weight in a young loblolly pine population. Silvae Genetica. 32:157-161.

Carvalho, S.P. de; Cruz, C.D. and Carvalho, C.G.P. de. 1999. Estimating gain by use of a classic selection under multicollinearity in wheat (*Triticum aestivum*). Genetics and Molecular Biology. 22:109-113.

Cruz, C.D. 1990. Aplicação de algumas técnicas multivariadas no melhoramento de plantas. Ph.D. Diss. Universidade de São Paulo,ESALQ, Piracicaba.

Cruz, C.D. 1997. Programa Genes: aplicativo computacional em genética e estatística. UFV, Viçosa.

Cruz, C.D. and Regazzi, A.J. 1994. Modelos biométricos aplicados ao melhoramento genético. UFV, Viçosa.

Dickerson, G.E.; Blunn, C.T.; Chapman, A.G.; Kottman, R.M.; Krider, J.L.; Warwick, E.J.; Whatley, J.A.Jr.; Baker, M.L.; Lush, J.L. and Winters, L.M. 1954. Evaluation of selection in developing inbred lines of swine. Missouri Research Bulletin. 551. University of Missouri, Columbia.

Filgueira, F.A.R. 1982. Manual de olericultura. Manual de comercialização de hortaliças. Agronômica Ceres, São Paulo.

Glendinning, D.R. 1963. The inheritance of bean size, pod size and number of beans per pod in cacao (*Theobroma cacao* L), with a note on bean shape. Euphytica. 12:311-322.

Godshalk, E.B. and Timothy, D.H. 1988. Factor and principal component analyses as alternatives to index selection. Theoretical and Applied Genetics. 76:352-360.

Hayes, J.F. and Hill, W.G. 1980. A reparametrization of a genetic selection index to locate its sampling properties. Biometrics. 36:237-248.

Harding, J.; Byrne, T.; Huang, H. and Yu, Y. 1991. Multi-trait selection in flower crops. p.157-178. In: Harding, J.; Singh, F. and Mol, J.N.M. (Eds.). Genetics and Breeding of Ornamental Species. Kluwer Academic, Boston.

Hazel, L.N. and Lush, J.L. 1942. The efficiency of three methods of selection. Journal of Heredity. 33:393-399.

Hotteling, H. 1933. Analysis of a complex of statistical variables into principal components. Journal of Education and Psychology. 24:417-441.

Lin, C.Y. 1978. Index selection for genetic improvement of quantitative characters. Theoretical and Applied Genetics. 52:49-56.

Mahalanobis, P.C. 1936. On the generalized distance in statistic. Proceedings of the National Institute of Science. 2:49-55.

Martin, S.K.St.; Loesch, P.J.; Demopulos-Rodriguez, J.T. and Wiser, W.J. 1982. Selection indices for the improvement of opaque-2 maize. Crop Science. 22:478-485.

Tourjee, K.R.; Harding, J. and Byrne, T.G. 1995. Interpretation of a selection plateau through complex segregation analysis: Euclidean distance index selection for flower colour in the Davis population of Gerbera. Heredity. 75:290-296.

Van Vleck, L.D. 1974. Notes on the theory and application of selection principles for the genetic improvement of animals. Cornell University, Ithaca.

Young, S.S.Y. 1961. A further examination of the relative efficiency of three methods of selection for genetic gains under less restricted conditions. Genetical Research. 2:106-121.

Wood, G.A.R. 1979. Manufactures need with respect to quality. Cocoa Grower's Bulletin. 28:4-6.