Rev. Brasil. Genet. 16, 1, 79-89 (1993)
(Brazil. J. Genetics)

COMPARISON OF GAINS FROM SELECTION AMONG CORN PROGENIES, BASED ON DIFFERENT CRITERIA*

Cosme Damião Cruz[1], Roland Vencovsky[2], Sebastião de Oliveira e Silva[3] and Geraldo Antonio Tosello[2]

ABSTRACT

A comparison was made of expected gains from selection among full-sib families of corn, assuming direct selection for each trait and simultaneous selection, based on the following indices: a) classic; b) base; c) with desired gains as weights; d) free of weights and e) based on sum of ranks. The number and type of main traits were taken in three different combinations.

The index based on desired gains, equivalent to one genetic standard deviation, was less efficient. Acceptable gains were obtained for the remaining index criteria. The classic index of Hazel and Smith showed slight superiority in terms of total gain and distribution of gains among traits. In this case, the genetic coefficients of variation taken as economic weights was found to be an acceptable alternative as a set of initial values.

INTRODUCTION

To maximize the success of breeding programs, researchers have utilized information about several traits for the selection of superior genotypes. To determine the superiority of a cultivar with respect to certain traits, visual examination alone is not sufficient, but additional information must be obtained from locally controlled trials, often repeated over time and locations, or from laboratory tests. Thus, large amounts of data need to be collected and duly analyzed to permit breeders to decide about culling

---

* Part of a thesis presented by C.D.C. to ESALQ/USP in partial fulfillment of the requirements for the Doctoral degree.

[1] Departamento de Biologia Geral, Universidade Federal de Viçosa, 36570-000 Viçosa, MG, Brasil. Send correspondence to C.D.C.

[2] Departamento de Genética, ESALQ/USP, Caixa Postal 83, 13418-900 Piracicaba, SP, Brasil.

[3] EMBRAPA/Centro Nacional de Pesquisa de Mandioca e Fruticultura (CNPMF), Caixa Postal 007, 44380-000 Cruz das Almas, BA, Brasil.

and/or selection as a function of statistical parameters which represent field information in a summarized form.

Since selection based on statistical parameters needs to be as effective as selection practice by good breeders on the basis of individual observations, the statistical tests used should involve as much information as possible. Within this context, the criterion of selection by indices is advantageous since it is based on the simultaneous combination of the information about all traits of interest and takes into account the genetic properties of the population under study.

Comparative studies of selection criteria have revealed that the use of the classic index proposed by Smith (1936) and Hazel (1943) is more advantageous than selection by the tandem method based on the selection of one trait at a time, or by the method of independent elimination levels which is based on the establishment of minimal (or maximal) levels for each trait, so that selection is made among individuals whose performance is between the desired level and the preestablished limit.

Despite its advantages, there are certain practical and methodological limitations to the use of the classic selection index (Lin, 1978). In view of the difficulties occasionally arising, several investigators have proposed alternatives to the classic index method or extension of the method so as to make it viable and to permit more frequent use by breeders. Thus, the following indices have been widely discussed in the literature, among others: restricted (Kempthorne and Nordskog, 1959), base (Williams, 1962), free of weights (Elston, 1963), based on desired gains (Pesek and Baker, 1969), multiplicative (Subandi *et al.*, 1973), and the index based on sum of ranks (Mulamba and Mock, 1978).

Examples of the use of indices in corn culture have been presented by Robinson *et al.* (1951), Subandi *et al.* (1973), Gutierrez (1974), Suwantaradon *et al.* (1975), Regazzi (1978), Kauffmann and Dudley (1979), Crosbie *et al.* (1980), Reis (1981) and ST Martin *et al.* (1986), among others. Additional studies demonstrating the relative superiority of the use of indices as selective criteria in several experimental situations are necessary to promote their routine use in plant breeding.

The objective of the present study was to compare expected gains from selection among full-sib families of corn by evaluating the response of several agronomic traits to direct and indirect selection and by evaluating the simultaneous response to selection using the following indices: classic index, base index, index with desired gains as weight, weight free index, and index based on sum of ranks.

MATERIAL AND METHODS

Material

One-hundred full-sib progenies obtained from the brachytic population "Piranão VF-1" were tested in randomized blocks with two replications in the

experimental field of the Department of Genetics of ESALQ, Piracicaba-SP, during the agricultural season 1984/85. The experimental plot consisted of 5.0-m long rows spaced 1.0 m apart, with plants spaced 0.20 m apart.

The traits studied were plant height, first ear height, ear yield, mean ear weight, ear length, mean 100-kernel weight, and kernel oil content.

Methodology

The efficiency of different selection indices in relation to direct trait selection was compared in three different situations: (I) ear yield and kernel oil content were established as major traits; (II) ear yield, mean ear weight, ear length, and mean 100-kernel weight were considered to be the major traits; (III) all of the traits were considered to be major. A major trait is that for which maximum gain is desired in the direction established by the breeder, and a secondary trait is that utilized only to help obtain gain in the major trait, with no economic weight in terms of index estimation.

Gain was estimated considering 20% selection intensity of the progenies tested. To quantify gain, the quotient $h^2 = \sigma_p^2/\sigma_f^2$ was used to measure heritability, with $\hat{\sigma}_p^2$ and $\hat{\sigma}_f^2$ being the estimators of genotypic and phenotypic variance among progenies, respectively. This heritability was used because the experimental units available did not permit the isolation of the additive component of genotypic variance.

The following selection alternatives were used:

(a) Direct and indirect response to selection

The direct gain in the ith trait was estimated by the expression $SG = h^2 DS_i$, and the indirect gain in the jth trait was estimated by the expression $SG = h^2 DS_{j(i)}$, where h^2 refers to heritability and DS_i to the selection differential applied to trait i. $DS_{j(i)}$ refers to the indirect selection differential obtained as a function of the means for trait j, whose superiority was demonstrated on the basis of trait i.

(b) Classic index

The classic index is established by the linear combination of the traits to be tested, in which the weighting coefficient vector is estimated by the expression $\hat{b} = p^{-1} Ga$, where P and G are the phenotypic and genotypic covariance matrices, respectively, and *a* is the vector of economic weights associated with the traits. In the present study, the economic weights adopted were those equivalent to the estimates of the genetic variation coefficients for the respective traits.

(c) Base index

This index also consists of a linear combination of traits whose weighting coefficients are the economic weights themselves (Williams, 1962). In the present case, the economic weights were the same as those utilized for the estimate of the classic index, thus permitting a comparison between them.

(d) Index with desired gains as weights

We adopted the index proposed by Pesek and Baker (1969) and generalized by Tai (1977) which includes secondary and major traits and requires the establishment of desired gains only for the latter. In the present study, the desired gain adopted was the equivalent to one genetic standard deviation for each major trait.

(e) Weight-free index

This index presents the structure $I = (Y_1 - K_1)\ (Y_2 - K_2)...(Y_n - K_n)$, where Y_i refers to the mean for the ith trait and K_i is the minimum (or maximum) value established for trait i, below (or above) which the individuals are culled. In the present study we considered K_i values equal to zero, so that the estimated index became identical to the multiplicative index proposed by Subandi *et al.* (1979).

(f) Index based on sum of ranks

This index is based on ranking treatments with respect to each trait in the order favorable to improvement. After classification, the ranks of each genetic material with respect to each trait are summed and the result is an additional measurement taken as the selection index (Mulamba and Mock, 1978).

The selective gain for trait i on the basis of any of the indices described above was estimated by the expression: $SG = h_i^2\ DS_{i(I)}$.

RESULTS AND DISCUSSION

Analysis of variance demonstrated the existence of significant genetic variability ($P < 0.05$) among progenies for all traits studied, except plant height and first ear height (Table I). This significance reflects a situation that is quite favorable to breeding since the heterogeneity of the population permits obtaining gains by selecting progenies of superior performance.

Table I - Summary of analysis of variance for eight traits tested in 100 full-sib corn progenies. Piracicaba, SP, 1984/85.

FV	d.f.	M.S.						
		Plant height	First ear height	Oil content	Ear yield	Mean ear weight	Ear length	100-kernel weight
Replications	1	1,326.5000	1,794.1250	0.0244	11.8144	1,177.5000	2.5000	45.9688
Progenies	99	351.4950^{NS}	228.5303^{NS}	0.2655**	2.9129**	902.8495**	244.9798**	20.8843*
Residue	99	306.6515	190.5000	0.0850	1.2423	665.3889	161.9343	13.0614
CV (%)		10.52	15.88	5.77	22.14	17.17	7.24	12.53

*, ** Significant at the 1% and 5% level of probability, respectively.
^{NS}, not significant.

The magnitude of selective gain and the relatively easy way in which it can be obtained can be predicted by the genetic parameters presented in Table I. It can be seen that, because of their higher heritability, there are better possibilities of obtaining percent gains for oil content and ear yield. This permits quite favorable selection since the progenies studied already present an experimental mean higher than 10 t/ha for ear yield and of 5.05% for oil content.

Commercial Brazilian corn hybrids present approximately 4 to 5% oil in their seeds, whereas commercial hybrids grown in the U.S. have as much as 6 to 7% oil content. Since corn oil has excellent dietary qualities, selection for this trait is of great interest in breeding.

Plant height and first ear height were the traits showing highest heritability. These traits are very important in corn culture since large losses occur during mechanical harvesting of tall plants due to drooping and breaking. The shorter height of brachytic progenies (Table II) represents a favorable characteristic of the population under study. With respect to ear insertion level, the progeny mean was also satisfactory since the ideal height is about 1.0 m, whereas a height of less than 0.6 m may cause problems during mechanical harvesting (Anderson and Crow, 1963). In the estimate of selection indices it was decided to consider these two traits as secondary, i.e., traits to be used only to help gain for the major traits, and small increases in their means were actually permitted.

Table II - Mean, maximum and minimum values, heritability (h^2), coefficient of genetic variation (CV_g) and genetic standard deviation (SD_g) estimated for seven agronomic traits in a population of 100 full-sib corn progenies. Piracicaba, SP, 1984/85.

Trait	Unit	Mean	Maximum	Minimum	h^2	CV_g	SD_g
Plant height	cm	166.95	200.00	137.50	12.76	2.84	4.73
First ear height	cm	86.92	120.00	69.50	16.64	5.00	4.36
Oil content	%	5.55	6.16	4.39	67.75	5.95	0.30
Ear yield	kg/5 m^2	5.03	9.05	2.60	57.35	18.15	0.91
Ear weight	g	150.21	200.80	103.80	26.30	7.25	10.90
Ear length	mm	175.66	206.60	141.70	33.90	3.67	6.44
100-kernel weight	g	28.82	36.40	19.80	37.46	6.86	1.98

Table III presents the gains estimated by direct and indirect selection of several traits. Percent gain by indirect selection was always lower than the value obtained by direct selection for all traits. Indirect selection produces higher gains on the right when selection intensity is the same and the product of heritability of the auxiliary trait by genetic correlation is higher than the heritability of the major trait (Falconer, 1981).

Ear yield permitted the highest percent gain (19.2%), followed by oil content and by 100-kernel weight. These estimates of gain are overestimates since the heritabilities used in the expressions of estimation were not narrow sense ones due to the fact that these were full-sib progenies, for which it was not possible to estimate separately the additive component of genotypic variance.

For oil content, 7.0% gain can be obtained, which provides a 5.4% expectation for the mean of the first cycle after recombination of the selected units. Other traits that may highly benefit from direct selection are ear weight and 100-kernel weight.

Although it provides maximal individual gains, direct selection does not permit obtaining satisfactory gains for the remaining traits. Thus, if only ear yield is selected for, the gain for this trait is the highest possible (19.2%) but the remaining traits would be at a disadvantage. For example, the gain for oil content would be only 1.4%, whereas the maximum gain obtained by direct selection would be 7.0%. Similar situations are observed with respect to the remaining traits. On the other hand, if selection were based only on oil content, there would be a reduction of ear yield and relatively low gains for the remaining yield components studied.

Table III - Estimates of selection gains (SG) obtained by direct and indirect selection of agronomic traits in 100 full-sib corn progenies. Piracicaba, SP, 1984/85.

Selection		Plant height (cm)	First ear height (cm)	Oil content (%)	Ear yield (kg/plot)	Ear weight (g)	Ear length (mm)	100-kernel weight (g)	Total
Plant	SG	2.34	2.38	-0.00	0.17	-0.27	0.20	0.03	
height	SG%	1.40	2.74	-0.02	3.49	-0.18	0.11	0.11	7.65
First ear	SG	2.15	2.67	-0.02	0.18	-0.10	0.23	-0.15	
height	SG%	1.29	3.07	-0.36	3.63	-0.06	0.13	-0.54	7.16
Oil	SG	-0.61	-0.73	0.35	-0.06	0.44	0.82	0.04	
content	SG%	-0.37	-0.84	6.97	-1.27	0.29	0.46	0.15	5.39
Ear	SG	0.59	0.50	0.07	0.97	3.28	0.84	0.52	
Yield	SG%	0.35	0.58	1.39	19.21	2.19	0.48	1.79	25.99
Ear	SG	0.59	0.44	0.01	0.61	7.99	3.79	1.14	
weight	SG%	0.35	0.51	0.18	12.14	5.32	2.16	3.94	24.60
Ear	SG	0.55	0.44	0.13	0.28	5.21	5.28	0.68	
length	SG%	0.33	0.51	2.66	5.48	3.47	3.01	2.36	17.82
100-kernel	SG	0.31	-0.03	-0.02	0.43	5.18	2.18	1.66	
weight	SG%	0.18	-0.03	-0.45	8.50	3.45	1.24	5.76	18.65

Table IV presents the gain estimates obtained by using the different indices in simulated selection. Three selection situations were used, each considering different numbers and types of major traits.

For situation (I) in which ear yield and oil content were considered to be the major traits, the base index was quite favorable, providing a sum of gains of 21.0% for these traits, which is higher than the sum obtained by direct selection for ear yield (20.6%) or for oil content (5.7%). In this situation, the classic index was comparatively less efficient since it provided a sum of gains of only 17.9% for the two traits, although it

Table IV - Estimates of selection gains (SG) obtained using the indices proposed by Smith (1963) and Hazel (1943) (classic), by Williams (1962) (base), by Pesek and Baker (1969) (desired gains, DG), by Elston (1963) (weight free,. FW), and by Mulamba and Mock (1978) (rank) for 100 full-sib corn progenies. Piracicaba, SP, 1984/85.

Index	Major traits*		Traits							Total	
			Plant height	First ear height	Oil content	Ear yield	Ear weight	Ear length	100-kernel weight	Major	General
Classic	I	SG	1.35	1.66	0.06	0.84	3.07	1.42	0.82		
		SG%	0.81	1.90	1.21	16.67	2.04	0.82	2.85	17.88	26.30
Base	I	SG	0.52	0.46	0.09	0.97	2.62	0.46	0.51		
		SG%	0.31	0.53	1.77	19.21	1.74	0.26	1.75	20.98	25.57
DG	I	SG	1.06	0.93	0.27	0.53	1.67	0.66	0.61		
		SG%	0.64	1.07	5.35	10.58	1.12	0.38	2.11	15.93	21.25
Classic	II	SG	0.84	0.67	0.03	0.83	4.87	2.35	1.21		
		SG%	0.51	0.77	0.67	16.50	3.24	1.34	4.19	25.27	27.22
Base	II	SG	0.55	0.45	0.01	0.57	7.92	4.30	1.18		
		SG%	0.33	0.52	0.20	11.29	5.27	2.45	4.10	23.11	24.16
DG	II	SG	0.32	0.02	0.03	0.64	3.55	3.61	1.06		
		SG%	0.19	0.03	0.66	12.66	2.36	2.06	3.70	20.78	21.66
Classic	III	SG	0.99	0.99	0.01	0.92	4.44	1.74	0.99		
		SG%	0.60	1.13	2.22	18.32	2.95	0.99	3.44	27.54	27.54
Base	III	SG	1.24	1.15	0.04	0.54	7.56	3.70	1.14		
		SG%	0.74	1.32	0.83	10.81	5.03	2.11	3.97	24.81	24.81
DG	III	SG	0.28	-0.40	0.20	0.48	-0.67	0.69	0.49		
		SG%	0.17	-0.46	3.91	9.47	-0.45	0.39	1.71	14.74	14.74
FW	III	SG	1.32	1.26	0.08	0.65	6.59	3.21	1.18		
		SG%	0.79	1.45	1.58	12.89	4.39	1.83	4.08	27.01	27.01
Rank	III	SG	1.38	1.33	0.08	0.47	6.76	4.09	1.11		
		SG%	0.83	1.53	1.53	9.44	4.50	2.33	3.86	24.02	24.02

* Major traits: I, oil content and ear yield; II, ear yield, ear weight, ear length and 100-kernel weight; III, all traits.

provided greater total gain and was more efficient in terms of higher gains for the remaining components of corn production (ear wieght, ear length and 100-kernel weight).

For situation (II) in which ear yield, mean ear weight, ear length and mean 100 kernel weight were considered to be the major traits, the classic index was particularly efficient both in terms of obtaining total gains and gains for each of the major traits.

For situation (III), in which all traits evaluated were considered to be major traits, the classic index was also particularly efficient. When compared to direct selection, the use of this index as a selection criterion provided a higher total gain than obtained by direct selection for ear yield, as well as a higher percentage of gain for five of the other six traits evaluated.

The index proposed by Pesek and Baker (1969), estimated on the basis of desired gains, proved to be inefficient in maximizing and/or distributing gains among traits in the various situations studied. This may have been due to the establishment of desired gains equivalent to one genetic standard deviation which, although recommended in the literature (Crosbie *et al.*, 1980; Vieira, 1988), may not have been the best option for the experimental conditions tested.

Lin (1978) reported that the use of the classic selection index may be rendered inviable by imprecisions in the estimates of the elements of phenotypic and genotypic covariance matrices involved. In view of the difficulties which occasionally arise and which limit the use of this index, several investigators have proposed alternatives that would make the method viable and that would permit its routine use in plant breeding. The base, (Williams, 1962), free of weights (Elston, 1963) and sum of ranks (Mulamba and Mock, 1978) indices, recommended in the literature because they are easy to estimate and especially because they do not require estimates of phenotypic and genotypic covariance matrices, provided satisfactory total gains. These gains, however, usually were of a slightly lower magnitude than those obtained by the classic index.

In general, it was demonstrated that the diversity of indices available permits the breeder to identify rapidly and efficiently the selective units that provide more favorable gain combinations. Since appropriate computation and software facilities for estimation are currently available, with consequent operational simplicity, there is no reason not to use these indices.

With respect to the classic index, even though its superiority is confirmed, a certain resistance to its use continues to exist because of the lack of preparation of many breeders in terms of establishing the relative economic weights of the various traits. In the present study, we determined the viability of establishing economic weights from the statistic estimated for the experimental data themselves. The use of the genetic variation coefficient (Table II) as a measure of the economic weight of each trait evaluated proved to be satisfactory and can be indicated for use in future studies or at least as a good reference point for weights in theoretical studies of selection indices.

ACKNOWLEDGMENTS

Publication supported by FAPESP.

RESUMO

Este trabalho teve por objetivo comparar os ganhos esperados obtidos por seleção em progênies de irmãs completas de milho, utilizando-se a seleção direta, em cada um dos caracteres avaliados, e a seleção simultânea, nos vários caracteres, por meio do uso de diferentes índices a saber: a) clássico, b) "base", c) o que utiliza ganhos desejados, d) "livre de pesos" e e) índice com base em soma de "ranks". Na estimação desses índices consideraram-se três situações, nas quais foram variados o número e o tipo de caracteres estabelecidos como principais.

Com exceção do índice baseado nos ganhos desejados, equivalentes a um desvio-padrão genético para cada caráter, os demais proporcionaram ganhos satisfatórios. O índice clássico de Smith e Hazel demonstrou ser o mais eficiente por proporcionar ganhos totais consistentemente superiores aos obtidos pela seleção direta e melhor distribuídos entre os caracteres.

Neste trabalho, utilizaram-se as estimativas do coeficiente de variação genético como medida dos pesos econômicos.

REFERENCES

Anderson, J.C. and Crow, P.W. (1963). Phenotypes and grain yield associated with brachytic-2 gene in single-cross hybrids of dent corn. *Crop. Sci. 3*: 111-113.

Crosbie, T.M., Mock, J.J. and Smith, D.S. (1980). Comparison of gains predicted by several selection methods for cold tolerance traits of two maize populations. *Crop. Sci. 20*: 649-655.

Elston, R.C. (1963). A weight-free index for the purpose of ranking or selection with respect to several traits at a time. *Biometrics 19*: 85-97.

Falconer, D.S. (1981). *Introdução à genética quantitativa*. (Tradução de Silva, M.A. e Silva, J.C.). Universidade Federal de Viçosa, Viçosa, pp. 279.

Gutierrez, A.D. (1974). *Estimação de índice de seleção para um composto de milho*. Masters Thesis. ESAL/USP, Piracicaba.

Hazel, H.N. (1943). The genetic basis for constructing selection indexes. *Genetics 28*: 476-490.

Kauffmann, K.D. and Dudley, J.W. (1979). Selection indices corn grain yield, percent protein, and kernel weight. *Crop. Sci. 19*: 583-588.

Kempthorne, O. and Nordskog, A.W. (1959). Restricted selection index. *Biometrics 15*: 10-19.

Lin, C.Y. (1978). Index selection for genetic improvement of quantitative characters. *Theor. Appl. Genet. 52*: 49-56.

Mulamba, N.N. and Mock, J.J. (1978). Improvement of yield potential of the Eto Blanco maize (*Zea mays* L.) population by breeding for plant traits. *Egypt. J. Gen. Cytol. 7*: 40-51.

Pesek, J. and Baker, R.J. (1969). Desired improvement in relation to selected indices. *Can. J. Plant Sci., 49*: 803-804.

Regazzi, A.J. (1978). Variâncias, covariâncias genéticas e índices de seleção num composto de milho (*Zea mays* L.). Masters Thesis, Universidade Federal de Viçosa, Viçosa.

Reis, F.P. (1981). Herdabilidade, correlações e índices de seleção em milho (*Zea mays* L.). Masters Thesis, Universidade Federal de Viçosa, Viçosa.

Robison, H.F., Comstock, R.E. and Harvey, P.H. (1951). Phenotypic correlations in corn and their implications in selection. *Agron. J. 43*: 282-287.

Smith, H.F. (1936). A discriminant function for plant selection. *Ann. Eugen. 7*: 240-250.

ST Martin, S.K., Loesch, P.J. Jr. and Hallauer, A.R. (1986). Heritabilities, correlations and index selection in BSBBS2 maize synthetic. *Maydica 31*: 325-333.

Subandi, W., Compton, A. and Empig, L.T. (1973). Comparison of the efficiencies of selection indices for three traits in two variety crosses of corn. *Crop. Sci. 13*: 184-186.

Suwantaradon, K., Eberhart, S.A., Mock, J.J., Owens, J.C. and Guthrue, W.D. (1975). Index selection for several agronomic traits in the BSSS2 maize population. *Crop. Sci. 15*: 827-833.

Tai, G.C.G. (1977). Index selection with desired gains. *Crop. Sci. 17*: 182-183.

Vieira, J.V. (1988). Herdabilidade, correlações e índice de seleção em populações de cenoura (*Daucus carota* L.). Doctoral Thesis, Universidade Federal de Viçosa, Viçosa.

Williams, J.S. (1962). The evaluation of a selection index. *Biometrics 18*: 375-393.

(Received October 4, 1991)