Proceedings of the Tenth Symposium of the International Society for Tropical Root Crops, held in Salvador, Bahia, Brazil, October 23-29, 1994

OPTIMIZING GENETIC PROGRESS BY USING SELECTION INDEXES IN A CASSAVA BREEDING PROGRAMME

C. Iglesias and E. Mesa*

Abstract

For 10 years, cassava-breeding programmes for different Colombian ecosystems have generated considerable information, which we used to define selection indexes to maximize genetic progress in dry matter productivity. We followed a four-step procedure: (1) through a stepwise procedure and factor analysis, we established that the following variables were highly determinant: harvest index, number of commercial roots, branching index, plant height, and leaf retention. (2) Heritability was estimated from a weighted regression analysis of traits evaluated on the same genotype in consecutive years. Except for the number of commercial roots and leaf retention, other component traits presented a heritability of >0.50. (3) To derive a selection index that maximized the expected genetic gain, we used the following methodologies: factor analysis with and without rotation, principal component analysis, and Smith's modified base index. All indexes assigned higher weights to harvest index, branching index, plant height, and number of commercial roots. Greater emphasis should be given to the enhancement of biomass, while maintaining an adequate plant architecture. (4) Current genetic progress has been based on increased root production and harvest index. Selection indexes, in contrast, provide more balanced criteria for improving the potential of cassava dry matter production.

Introduction

In practice, cassava-breeding procedures commonly involve selection for more than one trait. The trait of primary importance is usually root yield potential. Given the increasing importance of cassava processing, the concept of yield potential has evolved from fresh root yield to dry matter (DM) yield.

In the early 1980s, harvest index (HI) was reported to be the trait most directly related to fresh root yield (Kawano 1990). Later results confirmed this but also emphasized the need to concentrate efforts on traits determining the plant's capacity to produce carbohydrates and to store them (CIAT 1995; Iglesias and Hershey 1994). Fresh root yield and quality traits

* CIAT, A.A. 6713, Cali, Colombia.

segregated independently, making it possible to improve both simultaneously. Root yield is strongly related to the number of commercial roots and HI, and moderately related to carbohydrate source traits. Selection should therefore be done, not only for a high partitioning of the DM produced (HI), but also for a larger production of total biomass. Looking at heritability values, the expected progress for root yield could certainly be enhanced by incorporating other traits (i.e., source and partitioning) that are closely related to root yield and present higher heritability values. To optimize selection efficiency, different selection indexes should therefore be studied.

The use of a selection index in its broad sense is common. In most applied programmes, breeders use an empirical selection index. Several traits are observed and weighted intuitively by the breeder in the selection process targeted to particular growing conditions and markets. The genetic progress attained by a given programme will depend on the genetic base for the traits under consideration, the environmental influence on the expression of the traits, the accuracy with which they are measured, and the relative weights given by the breeder.

The objective of this work was to support cassava breeders' decisions through the definition of selection indexes that maximize genetic progress in DM productivity. We used information generated during 10 years of cassava breeding at CIAT.

Materials and Methods

The primary variable (objective) was dry root yield (DRY, t/ha), which was estimated as fresh yield x DM content. The secondary variables considered for building different functions were plant height (cm), number of stakes per plant, branching index, length (cm) of stems with leaves at harvest, HI, number of commercial roots, and cyanide content as determined by a qualitative method (scale of 1 to 9). The information used for this study corresponded to observational trials, preliminary yield trials, and advanced yield trials for 1980 to 1990.

Four different steps were considered in formulating the selection index that would provide the highest estimated genetic progress: (1) the variables to be included in the selection index to maximize DRY were determined, using a stepwise analysis (Draper and Smith 1981). The procedure introduced secondary variables into the multiple regression equation in the order of their relative contribution to DRY. (2) Heritability was estimated, using a regression analysis of traits evaluated in the same genotype in consecutive years. (3) Expected genetic progress for DRY was estimated by multiplying the selection differential by heritability of the traits. (4) Coefficients for different types of selection indexes were estimated. The objective of a selection index is to find a linear combination of phenotypic values that will maximize the expected genetic gain; in other words, the highest correlation between the index value and the true genetic value. The following estimation procedures were considered: (a) factor analysis without rotation of factors, (b) factor analysis with rotation of factors (Johnson and Wichern 1988), (c) principal component analysis, and (d) modified base index (Smith et al. 1981). To construct the last index, the phenotypic values were weighted by the estimated heritability, together with the economic weight:

$$I = w_i{*}P_1 + w_2{*}P_2 + ... + w_n{*}P_n$$

where

w_i is equal to the economic weight times the heritability for the trait.

All secondary variables chosen for the index were given a collective economic weight of one, because assigning a realistic figure for each was difficult. Thus, in effect, the index weighted the values only on the basis of heritability.

Results and Discussion

The correlations between DRY and the other variables were positive, high, and consistent with the number of commercial roots, HI, plant height, and the number of stakes per plant (Table 1). The results indicated that for breeding purposes, cassava is not a source- or a sink-limited crop and that the improvement of production potential should come from a balanced enhancement of both sink demand and source supply (El-Sharkawy et al. 1990).

The stepwise procedure defined a basic set of variables that should be considered when a selection index needs to be defined. In descending order of importance, these variables are HI, number of commercial roots, plant height, length of stems with leaves, and branching index. Equations including those traits explained >80% of the total observed variability for DRY. These variables should therefore be considered in a selection index to maximize genetic progress for DRY in cassava.

Plant traits are very important in determining the ability to multiply not only a genotype but also the root yield potential (Cock et al. 1979). Although the number of leaves (a major determinant of leaf area index) was not evaluated, the influence of plant height on final yield appears to be through a larger number of leaves. The search for short-internode genotypes could further enhance yield potential by making better use of available soil nutrients (CIAT 1995). The introduction of such genotypes may reduce the importance of plant height with respect to final yield and make it more relevant to record leaf or internode number.

Once trials are harvested, multivariate analysis can provide information on the relevance of traits, along with weights to construct genotypic scores that are highly correlated with the final objective the improvement of DRY (Table 2).

Traits such as HI, plant height, branching index, root DM, and cyanide content showed relatively high values for broad-sense heritability (Table 3). Similar information was reported by Bueno (1991) and Iglesias and Hershey (1994). Relatively greater genetic progress is expected for these traits, and they may also be considered as primary selection traits at early stages of a breeding programme when the evaluation is based on unreplicated plots. The number of commercial roots, length of stems with leaves, and fresh and dry root yields had intermediate to low heritability values. This certainly highlights the need to consider other traits particularly from the high-heritability group to enhance the response for the primary selection objective.

Figure 1 shows that the observed genetic progress for DRY throughout the period was 2.2%, after adjusting the linear regression line ($r = 0.64^{**}$). The estimated progress that could have been obtained, using the coefficient from factor analysis without rotation and selecting the same proportion of genotypes, as was done, would have been 3.1%. The index mainly increased the values (used to measure progress) in those years when the greatest progress for the conventional methodology was observed. Technically, the use of index selection provided a procedure that can be adjusted to the predominant relationship among traits at a particular site and according to season.

Conclusions

When large numbers of genotypes are handled in a cassava breeding programme, decisions as to which genotype should be kept or rejected are usually made in the field at harvest, normally on the basis of an empirical index the breeder has constructed, based on his or her experience. This study showed that some traits deserve more attention because they are correlated with the final goal and their heritability is relatively high. These two considerations usually fluctuate at a given site from season to season. Consequently, a more logical procedure would be to gather the information, conduct a factor analysis, determine the importance and relative weight that can be assigned to each trait, and then proceed to select, based on the scores. Other factors such as disease and pest resistance may then be considered, to adjust the final group of selected genotypes.

References

Bueno A. 1991. Estimación de los parámetros genéticos en la yuca. In: Hershey C, ed. Mejoramiento genético de la yuca en América Latina. CIAT, Cali, Colombia. p 197-220.

CIAT. 1995. Cassava Program 1993. Working document no. 146. Cali, Colombia.

Cock JH; Franklin D; Sandoval G; Juri P. 1979. The ideal cassava plant for maximum yield. Crop Sci. 19:271-279.

Draper NR; Smith H. 1981. Applied regression analysis. 2nd ed. John Wiley & Sons, New York.

El-Sharkawy M; Cock JH; Lynam JK; Hernández AP; Cadavid LF. 1990. Relationship between biomass, root yield and single-leaf photosynthesis in field-grown cassava. Field Crop Res. 25:183-201.

Iglesias C; Hershey C. 1994. Cassava breeding at CIAT: heritability estimates and genetic progress throughout the 80's. In: Ofori F; Hahn SK, eds. Proc. 9th ISTRC Symposium, Accra, Ghana. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. p 149-163.

Johnson R; Wichern D. 1988. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, NJ.

Kawano K. 1990. Harvest index and evolution of major food crop cultivars in the tropics. Euphytica 46:195-202.

Smith OS; Hallauer A; Russell W. 1981. Use of index selection in recurrent selection programs in maize. Euphytica 30:611-618.

Table 1. Correlations between dry root yield and other variables for cassava in each evaluation year.

Year	Variable						
	Commercial roots (no.)	**Harvest index**	**Branching index**	**No. of stakes/plant**	**Plant height (cm)**	**Stems with leaves**	**Cyanide content**
1980	0.39*	0.52**	-0.18	0.28	0.09	0.28	0.41*
1981	0.37**	0.26**	0.04	0.44**	0.42**	0.02	-0.15
1982	-	0.19*	-0.06	0.34**	0.28**	-0.07	0.12
1983	0.42**	0.41**	-0.07	0.22*	0.14	0.01	0.12
1984	0.48**	0.06	-0.12*	0.30**	0.53**	0.03	-0.03
1985	0.24**	0.09	0.18*	0.36**	0.19*	0.38**	-0.08
1986	0.56**	0.58**	-0.01	0.13*	0.11*	-0.13*	0.06
1987	0.72**	0.57**	-0.14*	0.21**	-0.11	-0.13	0.03
1988	0.70**	0.37**	0.07	0.43**	0.27**	0.05	0.16
1989	0.61**	0.48**	0.22**	0.05	-0.10	0.02	0.19*
1990	0.18**	0.21**	0.07	-0.03	0.03	-0.20*	0.03
Pooled	0.41	0.32	0.01	0.23	0.15	0.02	0.07

** = Significant at 5% probability level.*
*** = Significant at 1% probability level.*

Table 2. Correlation between dry matter (DM) yield in cassava and the scores generated by different indexes, and correlation between scores generated by the modified base index and the scores produced by the other procedures.

Methodology	**Correlation with DM yield**	**Correlation with modified base index**
Factor analysis without rotation	0.60**	0.33*
Factor analysis with rotation		
Principal component analysis	0.55**	0.63**
Modified base index		
	0.63**	0.33*
	0.11	-

 * = *Significant at 5% probability level.*
** = *Significant at 1% probability level.*

Table 3. Pooled estimates of broad-sense heritability for different traits in cassava.

Trait	**Pooled value**	**Max.**	**Min.**
Fresh root yield	0.34	0.74	0.13
Dry root yield	0.35	0.90	0.11
Dry matter content	0.66	0.94	0.41
Commercial roots (no.)	0.11	0.32	0.00
Harvest index	0.72	0.97	0.50
Plant height	0.53	0.82	0.35
Length of stems with leaves			
Branching index	0.29	0.62	0.00
Cyanide content	0.56	0.96	0.21
	0.51	0.84	0.24

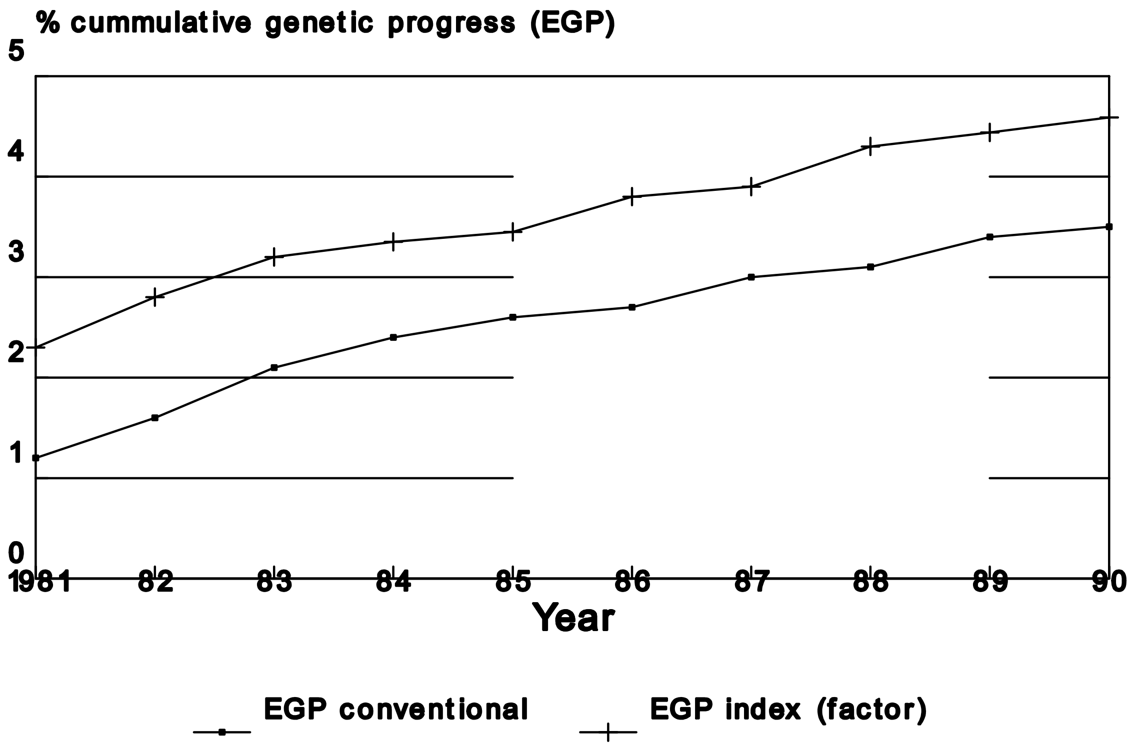

Figure 1. Cumulative expected genetic progress (EPG) for cassava DRY using conventional selection criteria and scores generated by factor analysis for a selection index.