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GENETIC DIVERGENCE IN SUGAR CANE (*Saccharum* spp.) CLONES*

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ABSTRACT

The degree and repeatability of genetic divergence of yield characteristics of the first two cuts among 20 sugar cane clones observed in two different environments in the sugar cane region of the State of Alagoas (Brazil) were evaluated by cluster analysis, Mahalanobis' generalized distance and Tocher's algorithm. Analyses were based on eight technological quality and yield characteristics. The clones tested did not show a high degree of divergence. A tendency toward less diversity was observed in the second cut. The repeatability of the results obtained under the different conditions was low, a fact that impairs the use of these data in future sugar cane breeding programs.

INTRODUCTION

Studies of genetic divergence using one or more multivariate techniques such as cluster, canonical and principal component analyses have been conducted over the last 20 years for several crops and with different objectives (Singh, 1981). The technique most often utilized in these studies is cluster analysis which is employed to group sampling units such as varieties, lines and clones, so as to obtain groups having the highest degree of within-group homogeneity and consequently heterogeneous in relation to one another (Johnson and Wichern, 1982).

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The main objective of canonical and principal component analyses is to reduce the dimensionality of the set of traits under study. These techniques permit a graphic representation of the dispersal of sampling units and the identification of groups having the same pattern of similarity. Cluster and canonical analyses are often associated in studies on divergence.

In studies on genetic divergence using cluster analysis, Mahalanobis' generalized distance (D^2) is commonly used as a measurement of proximity (Arunachalam, 1981) due to the fact that characteristics with different measurement units and normally correlated are being considered. The optimization method of Tocher is also frequently used as a clustering algorithm, as described by Singh and Chaudhary (1979).

In addition to being employed to evaluate the degree or magnitude of dissimilarity between pairs of materials, divergence analyses have been used to study the relationship between genetic divergence and several factors such as diversity of geographic origin (Jeswani *et al.*, 1970), kinship or ancestry of the materials (Bhatt, 1970), combining ability and heterosis (Raveendran and Appadurai, 1984; Shamsuddin, 1985). Divergence studies are also useful for the selection of parents in hybridization programs (Bhatt, 1973; Arunachalam, 1981).

The main limitations of genetic divergence analysis are the difficulty in interpreting the results because of the various traits involved, and the frequent lack of repeatability in different environments (years and locations) possibly because phenotypic values are considered, which are strongly affected by the environment (Murty *et al.*, 1973; Camussi *et al.*, 1985).

Few studies of genetic divergence have been carried out on sugar cane despite the potential use of the results for purposes such as parent selection (Punia *et al.*, 1983; Rao *et al.*, 1985), in view of the large number of clones existing in the germplasm banks of the institutions involved in sugar cane improvement.

One of the most important problems in sugar cane breeding is the narrow genetic basis of the materials normally used as parents, i.e., the high frequency of common ancestors in their genealogy which has led to a high degree of progeny inbreeding and to reduced variability (Peixoto *et al.*, 1984).

In order to stimulate progress in sugar cane breeding programs, Peixoto *et al.* (1984) suggested the use of new techniques in hybridization programs, including evaluation of exploitable variability. This could be done by means of studies of genetic divergence.

The objective of the present study was to evaluate the degree of divergence of performance of 20 sugar cane clones grown in different environments in the sugar cane-growing region of the State of Alagoas.

MATERIAL AND METHODS

The data were obtained in clone competition trials conducted in the State of Alagoas as part of the sugar cane breeding program of the "Núcleo de Absorção e Transferência de Tecnologia da Cooperativa Regional dos Produtores de Açúcar e Álcool de Alagoas" (Nucleus of Technology Acquirement and Transfer of the Regional Cooperative Association of Sugar and Alcohol Producers of Alagoas).

First- and second-cut data were obtained in two trials set up in different environments, both having red-yellow podzol soil of medium clay texture. Spacing between plants was 1.30 m in the São Simeão mill area (environment I), and 1.40 m in the Alegria mill area (environment II).

The experimental design consisted of randomized complete blocks with 20 treatments and four replications. The following clones were tested: SP70-1005, SP70-1143, SP70-1284, SP70-1423, SP70-3370, SP71-345, SP71-799, SP71-1406, SP71-3149, SP71-4156, SP71-4161, SP71-5574, SP71-6113, SP71-6163, CB45-3, Co331, Co997, CP51-22, RB70-194, and NA56-79.

The following traits were analyzed: percent brix of the extracted juice, percent pol of the extracted juice, percent cane fiber, percent cane pol, percent purity of the extracted juice, cane yield (t/ha), sugar yield (t/ha) and pol yield (t/ha).

Multivariate analysis of variance and the corresponding divergence analysis were applied to the data according to environment and cut. Mahalanobis' generalized distance and Tocher's algorithm were used in the analysis of divergence.

Spearman correlations between the distances obtained in the two environments in relation to one cut and between the distances obtained for different cuts in relation to the same environment were calculated by the method presented by Campos (1979). Nineteen clone pairs having the highest and lowest divergence were identified in each analysis in order to calculate the coincidence among the 19 most and least divergent clone pairs grown in the two environments in relation to the same cut, and in distinct cuts in relation to the same environment. The objective of these procedures was to test the repeatability of the prediction of divergence in environments and cuts.

RESULTS AND DISCUSSION

In all multivariate analyses, the null hypothesis for the vectors of clone effects was rejected at a level of significance of less than 1% ($P < 0.01$) by the Roy test, demonstrating the presence of variability or genotypic differences among clones in relation to the traits studied, regardless of environment or cut.

Tables I and II present the results of cluster analysis applied to first- and second-cut sugar cane in environment I. The most divergent clone pairs at first cut were SP71-6113 and CB45-3 ($D^2 = 63.4375$), SP71-6113 and Co331 ($D^2 = 60.7539$) and CB45-3 and Co997 ($D^2 = 56.2500$).

Table I - Clustering of 20 sugar cane clones tested in environment I in relation to the 1st and 2nd cut, using Mahalanobis' generalized distance and Tocher's algorithm.

Cluster	1st cut
I	SP70-1143, SP70-1284, SP70-3370, SP71-1406, SP71-3149, SP71-4156, SP71-4161, SP71-5574, SP71-6163, Co997, CP51-22, NA56-79
II	SP70-1423, Co331, RB70-194
III	SP71-345, SP71-799
IV	SP70-1005
V	SP71-6113
VI	CB45-3
Cluster	**2nd cut**
I	SP70-1005, SP70-1143, SP70-1284, SP70-3370, SP71-345, SP71-799, SP71-1406, SP71-3149, SP71-4156, SP71-4161, SP71-5574, SP71-6113, SP71-6163, Co997, CP51-22
II	SP70-1423, RB70-194, CB45-3
III	Co331
IV	NA56-79

CB45-3 presented high stalk production, with intermediate performance in terms of technological quality traits, a fact that explains its good and excellent pol/ha yield. SP71-6113 and Co997 were superior in terms of technological quality although their stalk production was lower than that of CB45-3, and their pol/ha yields were medium to high. Co331 also presented high stalk production although its performance in terms of technological traits was inferior.

Table II - Mean intra- and inter-cluster distances for sugar cane clones tested in environment I in relation to the 1st and 2nd cut.

Cluster	I	II	III	IV	V	VI
I	11.4251	25.8848	15.3651	15.0193	23.3654	34.3491
	(15.3665)	(58.2767)	(41.4219)	(26.7559)	-	-
II		10.7274	37.5788	22.0404	53.6936	16.8151
		(13.9840)	(56.1710)	(33.2050)	-	-
III			10.7031	26.1437	25.6025	43.6270
			(0.0000)	(33.4517)	-	-
IV				0.0000	46.7907	26.5898
				(0.0000)	-	-
V					0.0000	63.4375
					-	-
VI						0.0000
						-

[1] The values in parentheses refer to 2nd cut data.

The least divergent clones at first cut in environment I were SP71-4161 and CP51-22 (D^2 = 1.5052), SP70-1143 and NA56-79 (D^2 = 1.6055), and SP70-1143 and SP71-4156 (D^2 = 1.9297), all of them belonging to the same cluster (Table I).

The most divergent clones at second cut in environment I were CB45-3 and Co997 (D^2 = 109.6016), CB45-3 and SP70-3370 (D^2 = 101.4961), and CB45-3 and SP71-345 (D^2 = 95.5234). SP70-3370 and SP71-345 presented excellent performance in terms of technological traits but were inferior to CB45-3 (SP71-345 in particular) in terms of stalk yield and pol/ha. The most similar clones were SP71-1406 and SP71-4161 (D^2 = 0.7967), SP71-6163 and CP51-22 (D^2 = 0.8282), and SP70-3370 and Co997 (D^2 = 1.1184).

The correlation estimated between the distances obtained for the two cuts in environment I was 0.6496 (Table V). The coefficients of coincidence estimated for the 19 most and least divergent clone pairs at first and second cut were 0.3684 and 0.3158, respectively (Table VI). These values reveal low repeatability of the results, in agreement with the variation in cluster structure obtained for first- and second-cut material. However, in both analyses, some clone groups were classified in the same cluster as follows: SP70-1143, SP70-1284, SP70-3370, SP-71-1406, SP71-3149, SP71-4156, SP71-4161, SP71-5574, SP71-6163, Co997, and CP51-22; SP71-345 and SP71-799; SP70-1423 and RB70-194 (Table I).

Tables III and IV present the results of cluster analysis applied to first- and second-cut material in environment II. Again, there was variation in the classification structure between the two analysis, although some results such as classification in the same cluster of clones SP70-1005, SP70-1143, SP70-1284, SP70-3370, SP71-1406, SP71-3149, SP71-4156, SP71-6163, CB45-3, Co331, Co997, and RB70-194 were concordant (Table III). However, the small magnitude of the correlation between distances in the two cuts (r = 0.5207) and of the coefficients of coincidence in relation to the 19 most and least divergent clones in the two analyses (0.5789 and 0.1053, respectively) once again indicate low repeatability (Tables V and VI).

Table III - Clustering of 20 sugar cane clones tested in environment II in relation to the 1st and 2nd cut using Mahalanobis' generalized distance and Tocher's algorithm.

Cluster	1st cut
I	SP70-1005, SP70-1143, SP70-1284, SP70-3370, SP71-1406, SP71-3149, SP71-4156, SP71-6163, CB45-3, Co331, Co997, RB70-194
II	SP71-345, SP71-799, SP71-5574
III	SP70-1423, NA56-79
IV	SP71-4161
V	SP71-6113
VI	CP51-22
Cluster	**2nd cut**
I	SP70-1005, SP70-1143, SP70-1284, SP70-3370, SP71-345, SP71-799, SP71-1406, SP71-3149, SP71-4156, SP71-4161, SP71-5574, SP71-6113, SP71-6163, CB45-3, Co331, Co997, CP51-22, RB70-194, NA56-79
II	SP70-1423

Table IV - Mean intra- and inter-cluster distances for sugar cane clones tested in environment II in relation to 1st and 2nd cut.

Cluster	I	II	III	IV	V	VI
I	8.3426	10.8784	18.5603	18.5251	13.6364	25.5631
	(21.8102)	(54.6314)	-	-	-	-
II		7.2645	28.6030	10.3036	18.9241	15.1297
		(0.0000)	-	-	-	-
III			8.4917	39.4116	27.4669	45.1030
			-	-	-	-
IV				0.0000	24.9566	37.0352
				-	-	-
V					0.0000	24.0391
					-	-
VI						0.0000
						-

[1] The values in parentheses refer to 2nd cut data.

Table V - Estimates of Spearman correlation coefficients between Mahalanobis' generalized distances in different environments (E) and for different cuts.

Environment and cut	EI/cut 1	EII/cut 2
EI/cut 2	0.6496**	0.2911**
EII/cut 1	0.1745*	0.5207**

*P < 0.0001, and **P = 0.0164.

The clones with the highest degree of divergence at first cut in environment II were SP70-1423 and SP71-4161 (D^2 = 47.9880), SP70-1423 and CP51-22 (D^2 = 45.3506), and CP51-22 and NA56-79 (D^2 = 44.8555). SP70-1423 and CP51-22 showed medium to inferior performance with respect to technological and yield traits. NA56-79 and SP71-4161 showed intermediate to superior performance, with NA56-79 presenting the best performance in terms of stalk yield and pol/ha. The clones presenting the least divergence were SP70-1005 and SP71-4156 (D^2 = 1.1326), SP70-1005 and SP71-1406 (D^2 = 1.2375), and SP70-1005 and RB70-194 (D^2 = 1.5720).

Table VI - Coefficients of coincidence[1] between the 19 most and least[2] divergent clone pairs in different environments (E) and for different cuts.

Environment and cut	EI/cut 1	EII/cut 2
EI/cut 2	0.3684 (0.3158)	0.1053 (0.1579)
EII/cut 1	0.1579 (0.1579)	0.5789 (0.1053)

[1] Coefficient of coincidence = number of coincident pairs/19.

[2] The values in parentheses refer to the least divergent clones.

At second cut, the most divergent clones were SP70-1423 and SP71-6113 (D^2 = 84.1563), SP70-1423 and SP71-6163 (D^2 = 73.9648), and SP70-1423 and SP71-345 (D^2 = 66.9570). SP71-6163 presented good to excellent performance in terms of technological traits and yield. The closest clones were SP70-1143 and SP71-1406 (D^2 = 0.7814), SP71-799 and Co997 (D^2 = 1.5837), and SP71-799 and SP71-4156 (D^2 = 1.6802).

Analysis of the data obtained in different environments for the same cut also revealed variation in clustering structure (Tables I and III), i.e., incipient repeatability, as confirmed by the reduced magnitudes of the correlation and coincidence coefficients (Tables V and VI).

In the analyses of the first-cut data obtained in the two environments, SP71-6113 formed a separate group, revealing relevant divergence in relation to the remaining clones. SP70-1143, SP70-1284, SP71-1406, SP71-3149, SP71-4156, SP71-6163 and Co997, as well as SP71-345 and SP71-799, were classified in the same cluster, demonstrating their small divergence. When the second-cut data were analyzed, many clones continued to be classified in the same cluster, showing small divergence. SP70-1143, SP70-1284, SP70-3370, SP71-1406, SP71-3149, SP71-4156, SP71-6163 and Co997 were classified in the same cluster in all analyses (Tables I and III).

These results, taken together with the formation of a small number of clusters in the various analyses, one of which consisted of many clones, ranging in number from 12 to 19, demonstrate that the degree of divergence among the materials tested with respect to the traits under study was not high. This may have been due, in part, to the narrow genetic basis of these clones.

The smaller number of clusters obtained for second-cut data when compared to first-cut results reveal a tendency toward less divergence in second-cut material, possibly resulting from the fact that sugar cane clones are more uniform in terms of cycle to maturation during the stages following first cut.

The small or absent repeatability of the results of genetic divergence analysis may limit or prevent general conclusions, thus impairing the use of these data in programs of sugar cane breeding, such as the selection of parents to be used in hybridization programs. This frequent non-repeatability (Arunachalam, 1981) is partly due to the fact that phenotypic values are involved, but may also be due to the fact that the characteristics considered do not have the same discriminating power in different environments.

Thus, in order to avoid or minimize the problem of low or absent repeatability, discriminant analysis can be used to select from among all of the available traits those that contribute effectively to divergence among sampling units in all the environments considered, discarding the trait(s) that discriminate the sampling units in one, but not in another, environment. Another alternative is to take into account biochemical traits, which are little affected by environmental variation, exclusively or together with morphological, quality and yield traits.

Another option may be to select the traits and the environments where the materials are to be tested as a function of the objectives to be fulfilled. Finally, other methods of genetic divergence analysis may be used, such as that proposed by Camussi *et al.* (1985), whereby genetic distances are calculated on the basis of any estimable effect, such as heterosis, general or specific combining ability or progeny effects.

Despite the frequent non-repeatability of the results, studies of genetic divergence may be useful for parent selection among available materials, based on divergent and superior materials which complement each other in terms of one or more traits, since in this case greater heterosis or vigor is expected in the progeny, as well as more marked variability in segregant generations. However, it is of fundamental importance that the degree of divergence between two materials reflect differences of gene frequencies and the existence of gene effects due to dominance and epistasis.

CONCLUSIONS

Although variability existed among the clones tested, the degree of genetic divergence among them in relation to the traits studied was not high, a fact possibly due, at least in part, to the high frequency of common ancestors in their genealogies. Variation in clustering structure occurred in the analyses performed, revealing small repeatability of the results, especially between the two environments in relation to the same cut. This fact impairs the use of the results in programs of sugar cane breeding, especially in terms of parent selection.

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RESUMO

Avaliou-se o grau e a repetibilidade da divergência genética entre 20 clones de cana-de-açúcar, em dois ambientes na região canavieira do Estado de Alagoas, em relação aos dois primeiros cortes. Foi utilizada a análise de agrupamento, considerando-se a distância generalizada de Mahalanobis e o algoritmo de Tocher. As análises foram feitas com base em oito caracteres de qualidade tecnológica e de produção. Não se evidenciou grau acentuado de divergência entre os clones analisados. Houve uma tendência para menor diversidade em cana-soca. Foi pequena a repetibilidade dos resultados obtidos nas diferentes condições, dificultando o aproveitamento dos mesmos em programas de melhoramento desta cultura.

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