Theor. Appl. Genet. 56, 241-244 (1980)

THEORETICAL AND APPLIED GENETICS

Combining Ability and Parental Evaluation in Five Selected Clones of Sugarcane (*Saccharum* sp. Hybrids)*

K.K. Wu, D.J Heinz, H.K. Meyer and S.L. Ladd
Experiment Station, Hawaiian Sugar Planters' Association, Aiea, Hawaii (USA)

Summary. Five Hawaiian commercial sugarcane (*Saccharum* sp. hybrids) clones were crossed in a full diallel. Four morphological characters were studied in the progeny: number of millable stalks per plant, stalk diameter, stalk length, and sucrose content. A fifth character, plant volume, was calculated from stalk number, stalk diameter and stalk length. The five selected parental clones were treated as fixed variables in the analysis. General combining ability (gca) was significant for all five characters; specific combining ability (sca) was significant for stalk diameter, stalk length, and plant volume. The variance for gca was large in all progeny populations. However, the variance for sca was large in the progeny of only some clones and/or for some individual characters. Parents were evaluated on the basis of their general combining ability: clone H49-3533 had high gca for sucrose content, while clone H53-5356 had high gca for plant vigor.

Key words: Diallel analysis – Inbreeding depression – General combining ability – Specific combining ability

Introduction

The Hawaiian sugarcane breeding procedure incorporates new germplasm from clones of *S. officinarum, S. spontaneum, S. robustum, S. sinense*, and from foreign commercial clones into Hawaiian commercial hybrids. The progeny are then selected for yield potential in various environmental niches in Hawaii. The most desirable Hawaiian commercial clones do not flower under commercial field conditions and do not suffer a severe reduction in rate of growth during the cooler winter months or during the second year of the 2-year crop. They lodge without damage and have the ability to produce and maintain a heavy tonnage of stalks over the entire crop cycle (Warner 1953).

The incorporation of new germplasm into Hawaiian commercial clones is a slow process, and the breeding population is made up largely of advanced backcross lines and their derivatives. The chances of producing outstanding individual hybrids in such a population depend on the choice of parents; consequently, methods are needed to aid in evaluating potential parents.

Diallel analysis has been extensively used to evaluate parents for their general and specific combining ability (Sprague and Tatum 1942; Kehr 1961; Wilcox and Wilsie 1964; Kalloo and Bhutani 1974). Yang and Chu (1962) first reported the results of a half-diallel with four commercial sugarcane clones and mentioned that the variance component of specific combining ability (sca) was much larger than that of general combining ability (gca) for stalk number and cane yield, but not for stalk length. Hogarth (1973) conducted two full diallel experiments at two locations with the same five parents and concluded that the magnitude of the variance component for gca was not consistent when compared with that for sca for refractometer solids (Brix), number of stalks per stool, weight per stalk, and tons cane per acre. Miller (1977) found nonsignificant gca mean squares but significant sca mean squares for all characters studied in a half-diallel cross experiment at Canal Point.

Combining ability among selected parents depends on the type of gene action and the amount of potential genetic variability involved. Evaluation of parents for combining ability may facilitate the selection of parents and of crossing methods that could produce a great number of outstanding offspring. Polycrosses and biparental crosses are the two most important methods used in Hawaii.

The purpose of the present study was to estimate the variance components due to both gca and sca effects in the progenies produced by full diallel crosses of these clones and to identify good parental clones or crosses.

* Published with the approval of the Director as Journal Series Paper No. 455, Experiment Station, Hawaiian Sugar Planters' Association.

0040-5752/80/0056/0241/$ 1.00

Material and Methods

Five Hawaiian commercial sugarcane clones (H49-3533, H51-8029, H53-5356, H56-5840, H60-5657), selected from the breeding collection, were crossed in a full diallel, with reciprocal crosses maintained separately. For ease of reference, the clones were designated as clones 1-5, respectively. The crosses were made in isolation (large cloth bags) to avoid contamination from foreign pollen. Selfing may have occurred within crosses because all five varieties produce pollen. Seeds of 25 crosses and selfs were germinated in flats, and after approximately 3 months, the seedlings were transplanted to the field. The field design consisted of ten blocks, with a maximum of 25 randomized plots in each block. One plot consisted of ten plants per progeny, spaced 75 cm apart in a single row. Spacing between rows was 1.5 m.

Individual plants were measured for stalk number per plant (N), stalk diameter (D), stalk length (L), and refractometer solids, 8 months after transplanting. Stalk diameter and stalk length were based on the average of the measurements of two stalks from each plant (stalk diameter was measured at the center of mature internodes); stalk number was the number of millable stalks; and refractometer solids was the reading from a combined juice sample of three stalks per plant. Plant volume (v) was calculated from individual measurements of each plant ($v = \frac{\Pi}{4} D^2 LN$). Refractometer solids and plant volume represent indices for sucrose content and plant vigor, respectively.

Gardner and Eberhart's (1966) analysis III was employed except that block-to-block variation was not separated. This was because some crosses produced insufficient seed and a few blocks consequently contained fewer than 25 plots. Table 1 lists the sources of variation, identified by numerals. Plot means were used to compute the mean squares (1.) of selfs versus crosses, (2.) among selfs, and (3.) among crosses. The means of each cross were used to compute the mean squares of (4.) general combining ability (gca), (5.) specific combining ability (sca), and (6.) reciprocal differences. The plot means were the basis for the mean squares of (7.) plot-to-plot variation. The pooled variances of each plot constituted the (8.) plant-to-plant variation within a plot. The mean squares were converted to a single-plant basis by multiplying the mean squares of (1.), (2.), (3.), and (7.) with m, and those of (4.), (5.), and (6.) with mn; where m (= 9.15) is the average number of plants per plot; and n (= 9.01) is the effective number of plots per cross. The effective number of plots per cross was computed as $(r. - \Sigma r_i^2/r.)/(25-1)$; where r. is the total number of plots; r_i is the number of plots of the i^{th} cross; and i = 1, 2, ..., 25.

The variance components (Griffing 1956) for gca and sca, associated with the k^{th} parental clone, were estimated by:

$$\sigma^2_{g_k} = \hat{g}^2_k - \frac{p-1}{2p(p-2)} \frac{E}{mn'}$$

$$\sigma^2_{s_k} = \sum_{j \neq k} \hat{s}^2_{kj} / (p-1) - \frac{p-3}{2(p-1)} \frac{E}{mn'}$$

where $\hat{g}k$ is the estimate of gca effect for the k^{th} parental clone; $\hat{s}_{kj}$ is the estimate of sca effect for the k^{th} and the j^{th} parental clones; j, k = 1, 2, ..., p; p = 5; and E is the experimental error or the plot-to-plot mean square.

Results

The mean squares (on a single-plant basis) and the results of the F-test are given in Table 1. Plot-to-plot mean squares were used for the F-test. The progeny means for stalk number, stalk diameter, stalk length, plant volume, and refractometer solids for selfs, crosses, and reciprocals are given in Table 2. The means obtained from all crosses made with one common parent, excluding selfs, are shown in Table 3.

Differences betwee progeny means of selfs and crosses (including reciprocals) were highly significant for stalk number, stalk diameter, stalk length, and plant volume, but not for refractometer solids (Table 1). The progeny mean of selfs in general was lower than that for crosses (Table 2), indicating inbreeding depression for all characters except refractometer solids. Lack of inbreeding depression for refractometer solids was also reported by Hogarth (1973). Loss of vigor due to selfing was 5.7, 8.8,

Table 1. Mean squares from combining ability analysis of variance for a five-clone full diallel in sugarcance

Source of variation	df	Stalk Number	Stalk Diameter (cm)	Stalk Length (m)	Plant volume (dm^3)	Refractometer solids
1. Self vs. cross	1	1,056.54[b]	6.780[b]	20.069[b]	6,908.80[b]	36.98
2. Among selfs	4	86.08[b]	1.614[b]	4.902[b]	25.89	26.44
3. Among crosses	19	168.67[b]	1.336[b]	2.746[b]	302.37[b]	15.89
4. gca	4	588.50[b]	2.609[b]	5.723[b]	708.92[b]	35.48[a]
5. sca	5	35.35	0.676[b]	1.811[b]	154.10[b]	10.63
6. Reciprocal	10	75.65[b]	1.209[b]	2.244[b]	228.29[b]	11.55
7. Plot to plot error	202	17.58	0.174[b]	0.316[b]	63.85[a]	14.62[b]
8. Within plot error	1,839	16.43	0.123	0.161	51.77	3.59
Standard error per plot		1.38	0.138	0.186	2.63	1.27
Coefficient of variation		17.93	5.35	6.67	21.93	7.85

[a] and [b] indicate significance at the 0.05 and 0.01 probability levels, respectively

Table 2. Means of five characters for progeny obtained from selfing and crossing of five sugarcane clones

Selfs and crosses[a]	Stalk Number	Diameter (cm)	Length (m)	Plant volume (dm^3)	Refractometer solids
1 × 1	5.68	2.59	2.57	8.09	16.23
1 × 2	8.52	2.76	2.99	15.49	16.44
1 × 3	7.19	2.59	2.85	12.03	16.98
1 × 4	6.90	2.78	3.21	13.64	16.94
1 × 5	7.27	2.66	2.70	11.18	16.37
2 × 1	7.91	2.68	2.80	12.66	16.78
2 × 2	7.00	2.47	2.45	8.20	15.41
2 × 3	10.89	2.42	2.69	14.63	15.91
2 × 4	8.15	2.44	2.56	10.30	15.73
2 × 5	8.52	2.46	2.53	10.80	15.79
3 × 1	8.56	2.67	2.88	13.89	16.93
3 × 2	9.91	2.65	2.89	16.00	15.90
3 × 3	6.75	2.42	2.82	9.30	16.58
3 × 4	8.77	2.64	2.92	14.91	16.32
3 × 5	9.07	2.38	3.05	12.42	15.50
4 × 1	5.79	2.69	2.96	10.28	15.95
4 × 2	7.58	2.67	2.97	13.21	16.52
4 × 3	6.95	2.80	3.14	13.96	16.26
4 × 4	4.99	2.60	2.85	8.20	16.15
4 × 5	5.51	2.76	2.87	10.20	16.04
5 × 1	8.12	2.60	2.72	12.09	16.26
5 × 2	9.32	2.57	2.69	13.34	16.57
5 × 3	10.85	2.55	2.74	15.87	16.05
5 × 4	7.79	2.46	2.64	10.86	15.80
5 × 5	7.48	2.26	2.28	7.90	15.25
Average for selfs	6.38	2.46	2.59	8.33	15.92
Average for crosses	8.17	2.61	2.84	12.88	16.25

[a] 1 = H49-3533; 2 = H51-8029; 3 = H53-5356; 4 = H56-5840; 5 = H60-5657

21.9, and 35.3 percent for stalk diameter, stalk length, stalk number, and plant volume, respectively.

The effect of gca was significant for all five characters studied; the effect of sca was significant for stalk diameter, stalk length, and plant volume, and the effect of reciprocals was significant for all characters except refractometer solids (Table 1).

Natarajan et al. (1967) based the differences between a cross and its reciprocal in the sugarcane clones they studied mainly on maternal effect for stalk number, stalk length, and refractometer solids. Loh and Tseng (1950) reported that sucrose content may depend on the seed parent. Hogarth (1973) pointed out that, because the maternal parent of a cross is not emasculated, some self-pollination cannot be avoided unless the maternal parent is completely pollen sterile. The amount of selfing in a cross may be the main cause of reciprocal differences. In our study, maternal effect and the effect due to selfing cannot be separated from each other because it is not possible to determine the amount of selfing in a cross. Selfed progeny of clone 4 (H56-5840) had an average of 4.99 stalks, the lowest mean of all progenies examined (Table 2). The stalk numbers for crosses with clone 4 as the maternal parent were all low compared with most other crosses; this may have been caused by selfing.

Table 4 shows the estimates of variance for general (σ_g^2) and specific (σ_s^2) combining ability associated with each clone and for all characters studied. A small σ_g^2 value for a clone indicates that the clone is average in its general combining ability, while a large value indicates that the clone is either much better or much poorer than the remaining clones studied. A low σ_s^2 value for a clone indicates that hybrids involving this clone have performed as would be expected on the basis of their general combining ability, while a high value indicates that some combinations did relatively better or poorer than expected (11). Consider stalk number as an example. Clones 3 and 4 had large σ_g^2 values (Table 4), whereas clone 3 had the highest and clone 4 the lowest total progeny means (Table 3). Clones 3 and 5 had high σ_s^2 values (Table 4), whereas crosses 2 × 3, 3 × 2, and 5 × 3 had the highest and cross 4 × 5 the lowest progeny means (Table 2). In extreme cases, the wider the range of average performance of crosses involving a common parent (either seed or pollen parent), the larger the values will be for the variance of sca; the smaller the range for average performance, the larger the values will be for the variance of gca. Therefore, a high variance of gca indicates that the clone would be better used as parent in a polycross, while a high variance for sca indicates that the clone would be better used as parent in a biparental cross.

Table 3. Means of five characters for total progeny (except selfs) from each of five sugarcance clones

Clone	Stalk Number	Diameter (cm)	Length (m)	Plant volume (dm^3)	Refractometer solids
1. H49-3533	7.53	2.67	2.88	12.65	16.58
2. H51-8029	8.85	2.58	2.76	13.31	16.20
3. H53-5356	9.02	2.58	2.89	14.21	16.23
4. H56-5840	7.18	2.65	2.90	12.17	16.19
5. H60-5657	8.31	2.51	2.74	12.10	16.04

Table 4. Estimates of variance of general (σ_g^2) and specific (σ_s^2) combining ability for each of five sugarcane clones

Clone	Stalk number		Stalk diameter		Stalk length		Plant volume		Refractometer solids	
	σ_g^2	σ_s^2	σ_g^2	σ_s^2	σ_g^2	σ_s^2	σ_g^2	σ_s^2	σ_g^2	σ_s^2
1. H49-3533	0.760	0.069	0.0078	0.0009	−0.0005	0.0072	−0.007	0.537	0.169	−0.013
2. H51-8029	0.725	−0.012	0.0014	0.0017	0.0095	0.0023	0.209	0.186	−0.019	−0.010
3. H53-5356	1.283	0.089	0.0007	0.0019	0.0048	0.0056	3.009	0.499	−0.023	0.007
4. H56-5840	1.694	0.031	0.0032	0.0027	0.0078	0.0022	0.821	0.138	−0.017	−0.032
5. H60-5657	0.007	0.074	0.0054	0.0000	0.0164	0.0037	1.004	−0.063	0.051	−0.016

Discussion

In sugarcane breeding, the number of superior individuals in a progeny is very important. Because thousands of progenies from crosses are available for testing each year in Hawaii, only a small sample from a cross can be grown and evaluated for individual characteristics. Parents are chosen for further crossing on the basis of high sample mean and/or high sample variance in the progeny for the traits under consideration. Crosses low in both mean and variance are not repeated, because the chance of finding an outstanding individual is rare. Crosses with low mean but high variance are repeated if superior offspring are actually found in the progeny. If the sample variance is high, progeny size should be large because the sample variance fluctuates greatly among small samples (Wu et al. 1978).

When gca is more important in the progeny population, parents should be evaluated based on the variance of general combining ability; when sca is more important, parents should be evaluated based on the variance of specific combining ability. However, Kalloo and Bhutani (1974) came to the conclusion that selection based on average performance would be more reliable than selection based on the estimates of sca effects.

Because gca effects were important among the clones used in this study, those with high variance of gca should be selected for polycross. For instance: clone 1 (H49-3533) would be a good parent for high sucrose content and clone 3 (H53-5356) would be a good parent for plant vigor. If special crosses were selected, they should be selected on the basis of high mean and/or high within-plot variance; such crosses are 1 × 3, 3 × 1, 2 × 1, 1 × 4 for high sucrose content, and 1 × 2, 3 × 2, 3 × 4, 5 × 3 for high plant vigor.

The effect of self-pollination needs further study (Brown et al. 1969). However, because emasculation of sugarcane flowers is not feasible at present, we must accept the results as they are for the evaluation of parents and crosses for the given environment.

Literature

Brown, A.H.D.; Daniels, J.; Latter, B.D.H.; Krishnamurthi, M. (1969): Quantitative genetics of sugarcane. 3. Potential for sucrose selection in *Saccharum spontaneum*. Theor. Appl. Genet. 39, 79-98

Gardner, C.O.; Eberhart, S.A. (1966): Analysis and interpretation of the variety cross diallel and related populations. Biometrics 22, 439-452

Griffing, B. (1956): Concept of general and specific combining ability in relation to diallel crossing systems. Austr. J. Biol. Sci. 9, 463-493

Hogarth, D.M. (1973): Methods of selection and estimation of genetic variation in population of sugarcane. Ph.D. thesis, Univ. of Queensland, Australia

Kalloo, R.K.S.; Bhutani, R.D. (1974): Combining ability studies in tomato (*Lycopersicon esculentum* Mill.). Theor. Appl. Genet. 44, 358-363

Kehr, W.R. (1961): General and specific combining ability for four agronomic traits in a diallel series among six alfalfa clones. Crop Sci. **1**, 53-55

Loh, C.S.; Tseng, P.M. (1950): Notes on sugarcane mobilization methods. Proc. Int. Soc. Sugar Cane Tech. **9**, 677-694

Miller, J.D. (1977): Combining ability and yield component analyses in five-parent diallel cross in sugarcane. Crop Sci. **17**, 545-547

Natarajan, B.V.; Krishnamurthy, T.N.; Rao, J.T. (1967): Relative effects of parents on some economic characters in sugar cane. Euphytica **16**, 104-108

Sprague, G.F.; Tatum, L.A. (1942): General vs. specific combining ability in single crosses of corn. Agron. J. **34**, 923-932

Warner, J.N. (1953): The evolution of a philosophy of sugar cane breeding in Hawaii. Hawaiian Planters' Record **54**, 139-162

Wilcox, J.B.; Wilsie, C.P. (1964): Estimated general and specific combining ability effects and reciprocal effects in crosses among nine clones of alfalfa (*Medicago sativa* L.) Crop Sci. **4**, 375-377

Wu, K.K.; Heinz, D.J; Meyer, H.K.; Ladd, S.L. (1978): Minimum sample size for estimating progeny mean and variance in sugarcane progeny. Crop Sci. **18**, 57-62

Yang, T.C.; Chu, C.C. (1962): Evaluation of combining ability in sugarcane. Part 1. Report of Taiwan Sugar Expt. Sta. No. **26**, 1-10

Received July 30, 1979; Accepted October 12, 1979
Communicated by R.W. Allard

K.K. Wu, Assistant Plant Breeder
D.J Heinz, Director
H.K. Meyer, Associate Plant Breeder
Hawaiian Sugar Planters' Association
99-193 Aiea Heights Drive, P.O. Box 1057
Aiea, Hawaii 96701 (USA)

S.L. Ladd
Department of Agronomy Colorado State University
Ft. Collins, Colo. 80523 (USA)