RESEARCH ARTICLE

HETEROSIS AND COMBINING ABILITY OF SUGARCANE INBREDS FOR EARLY STAGE SELECTION TRAITS

A. Anna Durai* and G. Hemaprabha

Abstract

In a study on sugarcane cross derivatives involving inbreds and 'Co' clones, it was found that specific combining ability was more important than general combining ability for number of millable canes (NMC), cane thickness and HR brix. The inbred 1148-13-11-2-255 was the best general combiner for NMC, 1148-S5-242-3 for cane thickness and 1148-S4-242-1, 148-S5-242-3 and Co 0209 for HR brix. Contribution of line x tester interaction to the total variance for NMC was the highest (69.85%) followed by that of lines (29.48%). Lines (43.85%) and line x tester interaction (44.10%) contributed equally to the total variance for HR brix whereas lines (65.33%) contributed higher towards cane thickness. Among the inbreds, 1148-S5-242-3 was the best general combiner for cane thickness and HR brix, the selection criteria important for cane yield and sugar yield, respectively. Among the testers, Co 0209 was found to be a good combiner for HR brix. Three crosses, viz.1148-13-11-2-251 x Co 0209, 1148-13-11-2-255 x Co 62198 and 1148-13-11-2-255 x Co 775 were specific combiners for NMC. For cane thickness, 1148-S4-242-1 x Co 0209 was the best specific combiner. The crosses 1148-S5-242-3 x Co 0209 and 1148-S5-242-5 x Co 62198 were found to be the best specific combiners for HR brix. Superior specific combiners for NMC and cane thickness were of the crosses involving poor general combiners whereas those for HR brix were of both good and poor general combiners. The cross 1148-13-11-2-255 x Co 775 showed the highest desirable heterosis for NMC (85.28% relative heterosis and 58.00% heterobeltiosis) followed by 1148-S5-242-3 x Co 62198 (82.67% relative heterosis and 52.22% heterobeltiosis). The highest levels of relative heterosis (8.51%) and heterobeltiosis (4.08%) for cane thickness were recorded for 1148-13-11-2-251 x Co 62198. Crosses 1148-S4-242-1 x Co 0209, 1148-S5-242-3 x Co 0209 and 1148-S5-242-5 x Co 62198 recorded significant relative heterosis and heterobeltiosis for HR brix in the desired direction.

Keywords : Sugarcane, inbreds, combining ability, heterosis, millable canes, cane thickness, HR brix

Introduction

Sugarcane is grown as a commercial crop in both tropical and subtropical regions of India in 49.61 lakh ha with a productivity of 69.9 t/ha during 2015-16 (Anonymous 2016). Sugarcane improvement is a continuous process which involves hybridization and selection. The study of progenies resulting from hybridization in the crop is of great importance to identify desirable parents and measure the effectiveness of the selection among the progenies. Choice of parents can be determined by factors such as breeding goals, available materials, flowering time and breeding behaviour of parents in specific cross combinations and by the amount of information available on any parent or cross combinations. High levels of heterozygosity and polyploidy have made sugarcane breeding unpredictable and choice of parents difficult. However, Hogarth (1987) opined that although there is some imprecision, genetic analysis of traits is possible in sugarcane despite epistasis and polyploidy. Killick (1977) also observed that evaluation of combining abilities and genetic parameters are not greatly affected by ploidy level. While studying the inheritance of quantitative characters in sugarcane, Chen et al.

A. Anna Durai* and G. Hemaprabha
ICAR-Sugarcane Breeding Institute, Coimbatore 641007, Tamil Nadu, India
*Email: ayyadu@gmail.com

(1986) stressed the importance of evaluating the parents before attempting crosses. Cassalett et al. (1996) concluded that the genotypes generated through inbreeding can be reliable donors with predictable improved performance. One of the methods used to select the parental material for hybridization from the pool of genotypes and to identify their genetic worth is line x tester analysis. The mating is effected in all possible combinations keeping the sex of parent constant. The progenies resulting from line x tester mating, along with or without the parents, can be tested using suitable field design. Line x tester analysis has been applied to evaluate sugarcane with regard to quantitative characters (Punia 1986; Bakshi Ram and Hemaprabha 2000; Lourdusamy and Anbuselvam 2009; Alarmelu et al. 2010), red rot resistance (Bakshi Ram et al. 2005) and agronomic and biochemical characters (Tyagi and Lal 2005). Although several studies are available on combining ability and heterosis of sugarcane, studies using sugarcane inbreds as parents are lacking despite reports that inbreds transmit the characters of interest to their progeny with certainty and the breeding value of inbreds as parents can be measured precisely. Hence, the present study was undertaken to estimate the variance components, general and specific combining ability effects and heterosis in the progenies produced by line x tester crosses involving selected sugarcane inbreds and 'Co' clones for early stage selection traits, viz. number of millable canes (NMC), cane thickness and HR brix.

Materials and methods

The material for the study comprised five female parents (lines), namely the inbreds 1148-S_4-242-1 (L1), 1148-S_5-242-3 (L2), 1148-S_5-242-5 (L3), 1148-13-11-2-251 (L4) and 1148-13-11-2-255 (L5) and three male parents (testers), namely Co 62198 (T1), Co 775 (T2) and Co 0209 (T3). The female parents selected are advanced generation selfs of the sub-tropical variety Co 1148 and males selected are genotypes predominantly used as parents in the national hybridization programme. The selection of these parents was based on cane yield, sucrose content, resistance to red rot and flowering traits. The inbreds were pollinated with pollen from selected males to produce crosses. Line x tester matings made during the 2012 crossing season using five lines and three testers resulted in 15 F_1 crosses. The seeds of each cross were packed separately in plastic bags and stored at -20^{o}C. During September 2013, the seeds were germinated in trays which were transferred from the glasshouse after two weeks and kept in open environment for hardening. After hardening for three weeks, the seedlings were transplanted in the main field in randomized complete block design with two replications during mid-November 2013. From each cross and parent, 35 seedlings / settlings were transplanted in each replication. Data on NMC, cane thickness (cm) and HR brix (%) were taken at 11th month after transplanting. Analysis of variance was performed to calculate F values among the genotypes including crosses and parents. Line x tester analysis was carried out following the methodology described by Singh and Chaudhary (1985).

Results and discussion

Analysis of variance

Analysis of variance for the characters studied indicated genetic differences among genotypes. The significant variation due to parents and line x tester interaction (L x T) indicated heterotic response in the progenies of the crosses (Table 1). The estimates of variance due to specific combining ability (sca) and general combining ability (gca) and their ratio revealed that the former was higher than the latter for all the characters studied. This indicated the predominance of non-additive gene action controlling these characters. Similar trend was observed for several yield and quality parameters in earlier studies (Alarmelu et al. 2010; Lourdusamy and Anbuselvam 2005). However, Wu et al. (1980) reported predominance of gca effect for NMC, cane diameter, cane length and sucrose and Bressiani et al. (2002) for brix (%), cane yield, brix yield, stalk number, reaction to rust and pithiness. Additive and dominance gene action was reported by Hongkai (2009) and Bakshi Ram et al. (2005) respectively for stalk number and red rot resistance index. The gca effect which is attributed to additive gene action and additive x additive gene interaction is fixable. The non-additive type of gene action obtained in the present study could be exploited in hybrids since most of sugarcane varieties are F_1 hybrids between different selected parents. The difference in combining ability effects for the same traits, particularly observed among inbreds and between inbreds and other genotypes, may be attributed to difference in genetic constitution of the genotypes and their ability to transmit the same to their progenies.

The proportion of contribution of lines and testers, and their interaction to the total variance for different characters studied is presented in Table 2. Contribution of line x tester interaction to the total variance for NMC was the highest (69.85%) followed by that of lines (29.48%). The lower contribution of testers indicated that selection of lines with higher NMC would be more advantageous than selecting superior testers. Lines contributed higher towards cane thickness (65.33%) followed by line x tester interaction. The contributions of lines and lines x testers to the total variance for HR brix were 43.85 and 44.10%, respectively. These results were in partial

Table 1. ANOVA for Line x Tester design involving inbreds and Co clones for agronomic characters

Source	df	NMC	Cane thickness	HR brix
Replications	1	0.108	0.001	0.096
Genotypes	22	4.261^{*}	0.036^{**}	2.176^{**}
Lines	4	4.396	0.082	3.341
Testers	2	0.202	0.00	1.834
Lines x testers	8	5.209^{**}	0.02^{*}	1.68^{**}
Error	14	0.421	0.007	0.125
$\sum^2$sca		2.412^{**}	0.008^{*}	0.782
$\sum^2$gca		0.239	0.004	0.309
$\sum^2$sca / $\sum^2$gca		10.09	1.750	2.531

$^{*}P< 0.05$; $^{**}P<0.01$

Table 2. Proportion of contribution of lines (inbreds) and testers (Co clones) and their interaction to the total variance for agronomic characters

Source of variation	NMC	Cane thickness	HR brix
Lines	29.48	65.33	43.85
Testers	0.68	0.01	12.04
Lines and testers	69.85	34.66	44.10

agreement with those of Rai et al. (1991) who reported higher contribution of lines for NMC, cane diameter, cane length, single cane weight and stool weight; Tyagi and Lal (2005) who reported predominant effect of lines for cane thickness, testers for brix and line x tester interaction effect for NMC; Punia (1986) reported maximum contribution of lines to the total variance of cane diameter and line x tester interaction for NMC. Contribution of lines to the total variance, which is always high irrespective of the usage of inbreds in the present study and other genotypes in earlier studies, indicated that female parents and their interaction with male parents decide the variation among their progenies for these traits.

Evaluation of parents

General combining ability of parents for different characters is given in Table 3. The female parent 1148-13-11-2-255 was identified as a good general combiner for NMC, an important component trait of cane yield. All the genotypes having higher per se performance for NMC are not good general combiners. In this case, two genotypes, viz. 1148-13-11-2-251 and Co 62198 were good with respect to per se performance. However, gca effect of 1148-13-11-2-251 was negative while that of Co 62198 was positive. In case of HR brix, 1148-S4-242-1, 1148-S5-242-3 and Co 0209 were good general combiners. Among them, 1148-S4-242-1 and Co 0209 were better performing (per se) parents whereas 1148-S5-242-3 was not good with respect to per se performance. Similarly, Bakshi Ram et al. (2005) could not establish any correlation between gca and per se performance of parents for red rot disease index. The behavior

Table 3. General combining ability and per se performance of inbreds and Co clones

Parents	General combining ability			Per se performance		
	NMC	Cane thickness	HR brix	NMC	Cane thickness	HR brix
			Lines			
1148-S_4-242-1	0.090	-0.083*	0.860**	3.5	2.45	19.6
1148-S_5-242-3	0.357	0.183**	0.643**	3.0	2.75	17.6
1148-S_5-242-5	-0.960*	-0.083*	-0.040	4.0	2.50	16.0
1148-13-11-2-251	-0.677*	0.050	-0.707**	4.5	2.45	19.6
1148-13-11-2-255	1.190**	-0.067	-0.757**	5.0	2.50	19.9
			Testers			
Co 62198	0.163	0.001	0.217	4.5	2.25	18.7
Co 775	-0.097	0.003	-0.493	3.5	2.45	19.2
Co 0209	-0.067	0.001	0.277*	5.5	2.35	19.0

$^{*}P< 0.05$; $^{**}P<0.01$

of the parents with similar per se performance and different gca effects indicated non-additive gene action controlling the trait in question. However, 1148-S5-242-3 recorded higher per se performance for cane thickness which was also found as a good combiner for this trait. Similarly, a close relationship between per se performance and combining ability indicating predominance of additive x additive gene action was reported earlier (Alarmelu et al. 2010). Among the inbreds, 1148-13-11-2-255 was the best combiner for NMC and 1148-S4-242-1 and 1148-S5-242-3 were best for HR brix and these characters are important as selection criteria for cane yield and sugar yield, respectively. Among the testers, Co 0209 was found to be a good combiner for HR brix. These parents presumably possess relatively large number of favorable alleles for these characters and could be used in future programme for improving characters such as NMC, cane thickness and HR brix.

Evaluation of crosses

The specific combining ability effects of the inbred crosses are given in Table 4. Three crosses, viz. 1148-13-11-2-251 x Co 0209, 1148-13-11-2-255 x Co 62198 and 1148-13-11-2-255 x Co 775 were the best specific combiners for NMC. Although 1148-13-11-2-255 was a good general combiner for NMC, all the crosses involving this line were not superior specific combiners for this trait indicating that a parent with good gca effect need not necessarily produce better cross combinations. A parent with poor gca, however, might

Table 4. Per se performance and the effect of specific combining ability of the crosses involving inbreds of sugarcane

Crosses	Specific combining ability effects			Per se performance		
	NMC	Cane thickness	HR brix	NMC	Cane thickness	HR brix
1148-S_4-242-1 x Co 62198	0.700	-0.067	-0.950**	6.56	2.27	18.85
1148-S_4-242-1 x Co 775	0.130	-0.117	0.460	5.88	2.19	19.53
1148-S_4-242-1 x Co 0209	-0.700	0.183*	0.490	5.09	2.50	20.35
1148-S_5-242-3 x Co 62198	0.603	0.017	-0.683*	6.85	2.57	18.91
1148-S_5-242-3 x Co 775	-1.087*	0.067	-0.073	4.93	2.69	18.79
1148-S_5-242-3 x Co 0209	0.483	-0.083	0.757**	6.48	2.48	20.40
1148-S_5-242-5 x Co 62198	-0.880	-0.017	1.600**	4.04	2.32	20.53
1148-S_5-242-5 x Co 775	0.280	0.033	-0.990**	4.95	2.35	17.18
1148-S_5-242-5 x Co 0209 T3	0.600	-0.017	-0.610*	5.30	2.34	18.34
1148-13-11-2-251 x Co 62198	-1.713**	0.100	0.017	3.52	2.53	18.21
1148-13-11-2-251 x Co 775	-0.403	0.001	0.227	4.56	2.45	17.75
1148-13-11-2-251 x Co 0209	2.117**	-0.100	-0.243	7.13	2.39	18.01
1148-13-11-2-255 x Co 62198	1.420**	-0.033	0.017	8.50	2.33	18.18
1148-13-11-2-255 x Co 775	1.080*	0.017	0.377	7.93	2.32	17.87
1148-13-11-2-255 x Co 0209	-2.50**	0.017	-0.393	4.33	2.37	17.82

$^{*}P< 0.05$; $^{**}P<0.01$

also produce better hybrids (Tyagi and Lal 2005). In the present study, except 1148-13-11-2-255, all the lines and testers producing superior specific combiners are poor general combiners for NMC. For cane thickness too, the parents producing the best specific combiner (1148-S4-242-1 x Co 0209) were poor general combiners. The superiority of poor x poor general combiners to others might be due to over dominance and epistasis type of gene action influencing these traits. The crosses 1148-S5-242-3 x Co 0209 and 1148-S5-242-5 x Co 62198, which were good x good and poor x poor general combiners for HR brix, respectively were found to be the best specific combiners. These results indicated non-additive gene action for cane traits and both additive and non-additive gene action for HR brix.

Heterosis over better parent (heterobeltiosis), and mid-parent (relative heterosis) are given in Table 5. The relative heterosis for NMC varied from -22.22 (1148-13-11-2-251 x Co 62198) to 85.28% (1148-13-11-2-255 x Co 775) and heterobeltiosis from -22.22 (1148-13-11-2-251 x Co 62198) to 70.00 % (1148-13-11-2-255 x Co 62198). The seven crosses involving 1148-S4-242-1, 1148-S5-

Table 5. Percentage of relative heterosis and heterobeltiosis of crosses involving inbreds of sugarcane for agronomic characters

Crosses	Number of millable canes		Cane thickness		HR brix	
	Relative heterosis	Hetero-beltiosis	Relative heterosis	Hetero-beltiosis	Relative heterosis	Hetero-beltiosis
1148-S_4-242-1 x Co 62198	63.75**	45.56**	-4.26	-8.16	-1.57	-3.83*
1148-S_4-242-1 x Co 775	67.14**	67.14**	-10.20**	-10.20	0.77	-0.26
1148-S_4-242-1 x Co 0209	12.22	-8.18	4.17	2.04	5.44**	3.83*
1148-S_5-242-3 x Co 62198	82.67**	52.55**	4.00	-5.45	4.13*	1.07
1148-S_5-242-3 x Co 775	50.77**	40.00*	1.92	-3.64	2.17	-2.08
1148-S_5-242-3 x Co 0209	52.94**	18.18	-1.96	-9.09*	11.48**	7.37**
1148-S_5-242-5 x Co 62198	-4.71	-10.00	-3.16	-8.00	18.16**	9.63**
1148-S_5-242-5 x Co 775	32.00*	23.75	-5.05	-6.00	-2.27	-10.42**
1148-S_5-242-5 x Co 0209	11.58	-3.64	-5.15	-8.00	4.86*	-3.42
1148-13-11-2-251 x Co 62198	-22.22	-22.22	8.51*	4.08	-4.70**	-6.89**
1148-13-11-2-251 x Co 775	13.75	1.11	0.00	0.00	-8.51**	-9.44**
1148-13-11-2-251 x Co 0209	42.00**	29.09*	-2.08	-4.08	-6.48**	-7.91**
1148-13-11-2-255 x Co 62198	78.95**	70.00**	-3.16	-8.00*	-5.70**	-8.54
1148-13-11-2-255 x Co 775	85.28**	58.00**	-5.05	-6.00	-8.70**	-10.30**
1148-13-11-2-255 x Co 0209	-17.14	-20.91	-3.09	-6.00	-8.23**	-10.30**
SE	0.537	0.620	0.078	0.089	0.295	0.340
CD 95%	1.152	1.331	0.166	0.231	0.632	0.877
CD 99%	1.599	1.847	0.192	0.266	0.729	1.013

$^{*}P< 0.05$; $^{**}P<0.01$

242-3, 1148-13-11-2-251, 1148-13-11-2-255, Co 62198, Co 775 and Co 0209 showed the highest desirable heterosis for NMC. The range of relative heterosis and heterobeltiosis for cane thickness were -10.20 to 8.51 and -10.20 to 4.08%, respectively. The highest extreme was exhibited by the cross 1148-13-11-2-251 x Co 62198 while the lowest extreme was by 1148-S4-242-1 x Co 775 for both types of heterosis. Interestingly, the cross 1148-13-11-2-251 x Co 62198 recording the lowest level heterosis in negative direction for NMC showed the highest level of heterosis in positive direction for cane thickness but the same relationship was not applicable to all the crosses. Heterosis for HR brix ranged from -8.70 to 18.16% (relative heterosis) and -10.42 to 9.63% (heterobeltiosis). Among the 15 crosses, the three crosses 1148-S4-242-1 x Co 0209, 1148-S5-242-3 x Co 0209 and 1148-S5-242-5 x Co 62198 recorded significant and desirable heterosis for HR brix. Similar variation in heterosis for yield related stalk traits has already been reported earlier (Aitken et al. 2008).

Overall, the present study revealed that the inbreds 1148-13-11-2-255, 1148-S_5-242-3, 1148-S_4-242-1 and 1148-S_5-242-3 and a 'Co' clone Co 0209 emerged as good general combiners for early stage selection traits in sugarcane. Crosses involving inbreds, viz. 1148-13-11-2-251 x Co 0209, 1148-13-11-2-255 x Co 62198 and 1148-13-11-2-255 x Co 775 for NMC, 1148-S_4-242-1 x Co 0209 for cane thickness, and 1148-S_5-242-3 x Co 0209 and 1148-S_5-242-5 x Co 62198 for HR brix were identified as the best specific combiners. Both the categories of crosses, viz. good x good general combiners and poor x poor general combiners produced better specific combiners for the traits studied. Three crosses, viz. 1148-S_5-242-3 x Co 62198 and 1148-S_5-242-5 x Co 0209 were found with significant heterosis in the desired direction for NMC and HR brix. The best general and specific combiners and the crosses with high heterotic effects identified in the study could be exploited in future breeding programmes.

Acknowledgements

The authors are thankful to the Director, ICAR-Sugarcane Breeding Institute, Coimbatore, and the Head, Division of Crop improvement, for their academic encouragement and logistic support provided during the course of the study. The authors are also thankful to Mr. S. Thangasamy for his support during the execution of the research work.

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Received : 08 July 2016; Revised & Accepted : 31 December 2016