RESEARCH ARTICLE

DEVELOPMENT OF SUGARCANE VARIETIES FOR ABIOTIC STRESSES SUITABLE FOR SUB-TROPICAL CONDITIONS

Bakshi Ram

Abstract

Results of a number of experiments conducted under different abiotic stresses (water stress, waterlogging and salinity) prevailing in sub-tropical Indian conditions are presented in this article. Clones (T) showed significant differences for all traits studied indicating existence of enough genetic variability in the breeding material. There was significant effect of environments (E), i.e. stresses and crops (plant and ratoon crops), on the mean performance of clones for all the traits studied. This effect of E was split into effects of abiotic stresses (S), crops (C) and their interaction (S x C). The significant effect of 'C' for all the 6 traits indicated that the mean performance of clones was affected by crops i.e. plant and ratoon crops. The effect of stresses 'S' was also significant for all traits. This indicated that S affected the mean performance of clones with respect to sugar yield and its traits. Mean sugar yield and stalk yield showed reduction under all abiotic stresses studied. There was no effect of stress conditions on CCS %, pol % at 10th month and HR Brix at 8th month. Pol % at 12th month showed reduction only under water logging condition but CCS % was not affected adversely mainly because of increase in purity % due to forced maturity of stalks. Stalk yield related traits showed more variations under different abiotic stresses in comparison with juice quality traits. Hence, selection for juice quality traits would be easier and effective than selection for stalk yield traits under abiotic stresses. Results on genetic stocks, tolerant clones, relative response to selection, unified concept of stress breeding are also discussed. The maximum reduction under restricted irrigation (RI) was observed in Brix yield (31%) in GC-I, SSW, stalk yield and Brix yield (23%) in GC-II and in stalk yield (26%) in GC-III. The reduction in SSW was mainly due to reduced stalk length under RI conditions, which resulted in decreased stalk and Brix yields. Intermating amongst ISH-135 and ISH-152 on one hand and ISH-156 and ISH-175 on the other might result in isolation of desirable genotypes for saline conditions with higher stalk yields and good juice quality but with low concentrations of K and Cl in juice. Three clones viz, SES-222, SES-275 and SES-352 showed similar performance in normal and raifed (RF) environments with respect to SSW, stalk diameter, juice extraction % and Brix % and showed least reduction in stalk length. The clones viz. Co 89029, Co 90022, B 256 and IGH 442 were identified as genetic stocks for better ratoonability on the basis of trials conducted at three locations.

Introduction

Sugarcane is an important cash crop of India. Water stress is faced by sugarcane crop during the pre-monsoon period throughout the country. The crop, depending upon the region, experiences many harsh conditions through out the year. About 8.6 m ha Indian land is salt affected whereas about 4.7 m ha area in Indo-Gangetic plains is water logged during the monsoon period. Hence, sugarcane is grown in fluctuating climates, which cause drought, heat, cold, salt and water logging stresses and are combined with sub-optimal soil environments that generally limit its productivity. To augment this vulnerable situation, plant breeders, physiologists and agronomists are constantly on the search for genotypes that impart tolerance to an array of biotic and abiotic stresses. Although manipulating crops or their environments in ways that avoid or reduce stress injury can increase the productivity, development of crop plants to withstand unfavourable environments could be a better approach. Selection of parents for use in hybridization programmes is the first

Bakshi Ram
Director,
ICAR - Sugarcane Breeding Institute, Coimbatore – 641 007

step towards the process of improvement of crop plants. Sugarcane clones have been screened under different abiotic stress conditions like water stress (Johari et al. 1998), rainfed (Bakshi Ram et al. 1993; Singh et al. 1992), waterlogging / flooding (Goswami and Singh 1998, Sukhchain et al. 1997) and salt stress (Dang et al. 1998) and tolerant clones have been identified.

The optimum temperature for sugarcane growth is about 35^{o}C, and non-freezing temperatures under 20^{o}C will significantly curtail growth and yield (Moore 1987). The risk of freezing damage is one of the major limitations to growing sugarcane at latitudes more than 30^{o} from the equator. However, Bakshi Ram et al. (2001) identified nine progenies involving *Erianthus arundenaceus*, as one of the parents, which showed increase in stalk length during winter months over the better standard Co 1148. In North India, the temperatures during winter season may go as low as 0 - 5 ^{o}C which limits ratoonability of crop. Genetic improvement for ratoonability under such harsh conditions is much more important in this region than in tropical India.

Breeding for component traits is an ideal approach to improve sugar yield in sugarcane. Earlier studies have indicated that relationships among component traits have been affected by different genetic background of populations (Bakshi Ram and Hemaprabha 1991, 1997), crop age (Milligan et al. 1990), water stress (Bakshi Ram et al. 1995), flooding (Sukhchain et al. 1997), and selection methods (James 1971; Bakshi Ram et al. 2000). This makes the selection process more complicated and hence the development of sugarcane varieties, tolerant to abiotic stresses, becomes a tedious job for sugarcane breeders.

Materials and methods

Experiment 1

Thirty clones of sugarcane were evaluated in 4 environments representing water stress (WS), water logging (WL), salinity (SS) and normal (N) conditions. These clones included 22 'Co' and 'Co-allied hybrids, 2 *S. barberi* and 6 inter-specific hybrids (ISH). First plant crop experiments were planted in randomized block design during March, 1999 with 3 replications. These trials were ratooned at 12-month crop age to study the ratoonability of clones. A fresh set of second plant crop experiments (as above) was planted during next March, 2000. The plot size was 2-rows x 4m x 0.75m in all the experiments. WS condition was created by withholding irrigations during pre-monsoon period (April to June) till 50 % of the clones showed permanent leaf rolling even at the time of sunrise. WL condition was created during southwest monsoon period by flooding the experimental area with irrigation water till 50% of clones showed complete senescence. About 1½ feet water was kept stagnated in the experimental area during 1st July to 15th September. SS condition was created before planting by applying saline solutions (120 meq / l) in the quantities sufficient to salinize at least 60 cm of the topsoil. NaCl, $CaCl_2$ and $MgSO_4$ salts were used in order to have Na:Ca:Mg as 6:2:2 and Cl: SO_4 as 8:2 on milli-equivalent (meq) basis, which is typical of chloride type saline conditions in the sub-tropics (Kumar and Bakshi Ram 1996). In ratoon crop salt solution was applied just after completing the ratooning operations. Under N environment, the experimental crops were irrigated at 10 days interval during pre-monsoon period, as recommended in the Haryana state.

Experiment 2

More than 800 clones each of three open pollinated populations (general crosses) were evaluated under normal and restricted irrigated conditions. Ten seedlings were transplanted in a row of 6 m length at spacing of 60 cm. Under normal irrigated conditions, the experiment was irrigated at an interval of 10 days during pre-monsoon period whereas an interval of 30 days was maintained under restricted irrigated condition. Observations on number of millable stalks (NMS), stalk diameter, stalk length, single stalk weight (SSW) and HR Brix were recorded on per clump basis on randomly taken 200 clones. Stalk yield and Brix yield were computed utilizing above primary traits.

Experiment 3

In this experiment 11 progenies each of *S. barberi* (HB) and *S. spontaneum* (HS) crossed with commercial hybrids were evaluated in randomized block design under artificially created salinity condition. Saline condition was created as explained in Experiment 1, above. Data on six traits of stalk yield and juice and the availability of Na, K and Cl were recorded and analyzed by following standard procedures.

Experiment 4:

Fifteen clones of *S. spontaneum* were evaluated under normal irrigated and rainfed conditions in randomized block designs. Plot size was 2-rows x 4.5m x 0.9m. Rainfed plot was not irrigated after 60 days of planting, i.e. germination and initial establishment. Observations on nine traits of stalk yield and juice quality were recorded and analyzed by following standard procedures.

Experiment 5:

In order to combine the resistance/tolerance genes from different sources in the sugarcane clones and to identify elite clones with regeneration potential under low temperature conditions of the North West Zone, a large number of seedlings and sugarcane clones derived from different genetic backgrounds were evaluated during 2000 – 2006 at Karnal. Half of plots were ratooned during winter (last week of December) and remaining half plots were ratooned during spring (March). Observations on sprouting %, number of shoots / m and maximum shoot length were recorded after 45 days of ratooning.

Observations recorded in all the four experiments were analyzed for mean, variability and correlations coefficients by following standard statistical procedures.

Results and Discussions

Experiment 1

The pooled analysis of variance for sugar yield and its five traits is presented in Table 1. All the clones (T) showed significant differences for all traits studied indicating existence of enough genetic variability in the material and hence the scope for selection of clones from the population. There was significant effect of environments (E), i.e. stresses and crops, on the mean performance of clones for all the traits studied thereby indicating the existence of environmental variation under which these experiments were conducted. This effect of E was partitioned into effects of stresses (S), crops (C) and their interaction (S x C). The significant effect of 'C' for all the 6 traits indicated that the mean performance of clones was affected both by plant and ratoon crops. The effect of stresses S was also significant for all the studied traits. S affected the mean performance of clones with respect to sugar yield and its traits. Significance

Table 1. Pooled analysis of variance for sugar yield and its traits in sugarcane

Source	D.F.	Mean sum of squares					
		Sugar yield	**Stalk yield**	**NMS**	**Pol %**	**Purity %**	**HR Brix**
Clones (T)	29	65.89**	4311.99**	20278.37**	41.09**	242.62**	72.48**
Experiments (E)	11	116.28**	7933.57**	6137.05**	40.34**	123.65**	39.91**
Stresses (S)	3	86.53**	6203.29**	5882.57**	5.69**	206.64**	3.15*
Crops (C)	2	373.77**	23423.99**	18647.91**	160.13**	177.32**	137.75**
S x C	6	45.32**	3635.24**	2093.99**	17.74**	64.27**	25.67**
E x T	319	7.59**	557.53**	711.32**	2.29**	11.19**	3.21**
S x T	87	5.84**	429.48**	685.44**	1.89*	13.04**	2.75**
C x T	58	22.62**	1569.40**	2046.02**	4.93**	20.25**	5.34**
S x C x T	174	3.46**	284.26**	279.35**	1.61	7.25	2.74**
Error	718	0.89	59.18	64.09	1.17	5.36	1.08

of S x C interaction for all the traits indicated that S influenced C means. Variation due to different crops in all the traits (except purity %) was the main cause of variation in E whereas variation due to stresses was the second important cause for E variance for sugar and stalk yields and NMS, whereas for pol % and HR Brix interaction effect of S by C was the second important cause of E variance.

The mean response of clones to different environmental treatments (E x T) also varied significantly for all the six traits. This revealed the differential response of clones to various environmental treatments, i.e. stresses and crops as also reported earlier by Jackson and Hogarth (1992), Mirzawan et al, (1994) and Rattey and Kimbeng (2001). The effect of E x T was partitioned into effects of S x T, C x T and S x C x T. S x T interaction was significant for all characters. This indicated the differential response of clones for the six traits under different stress conditions. The significance of C x T interaction for all traits indicated the differential response of individual clones in ratoon and plant crops. The S x C x T interaction was significant for both sugar and stalk yields, NMS and HR Brix. This indicates the differential response and performance of individual clones for sugar and stalk yields, NMS and HR Brix, in three crops, which was further influenced by various stress environments. Insignificant S x C x T interaction for pol % and purity % at 12m indicated that selection for these juice quality traits would be more effective. Crops by clones (C x T) effect was

Table 2. Mean performance of 30 sugarcane clones for ten traits under 4 environments

Character	Normal	Mean		Salinity
		Water stress	Water logging	
Sugar yield (kg/plot)	4.26[a]	3.70[b]	4.30[a]	4.64[c]
Stalk yield (kg/plot)	38.88[a]	34.0	38.55[a]	44.29[c]
Pol % (12m)	15.98[a]	15.9	16.09[a]	15.54[b]
HR Brix (8m)	17.81[a]	17.8	17.88[a]	17.10[b]
NMS/plot	62.12[a]	60.0	64.79[c]	60.42[ad]
Stalk diameter (cm)	2.02[a]	1.97	1.88[b]	2.07[a]
Stalk length (cm)	193.7[a]	176.	204.7[c]	189.0[a]
SSW (kg)	0.65[a]	0.60	0.63[ab]	0.75[c]
Percent increase in stalk length	396.6[a]	378.	27.98[c]	330.5[d]
Percent increase in tillers/clump	100.7[a]	72.7	199.9[c]	123.5[d]

Within rows, means followed by the same letter are not-significant different at P = 0.05

the most important cause of E x T variance for all traits. Rattey and Kimbeng (2001) also reported genotype x crop year as the most important cause of G x E followed by G x location x crop year and G x location effects. However, for sugar and stalk yields, NMS, pol % and purity % variation due to S x T effects was the next important cause of E x T variance. Both S x T and S x C x T effects were equally important causes of variation in E x T for HR Brix at 8 m.

The mean performances of 30 clones for various characters under abiotic stresses are presented in Table 2.

Effect of water stress on mean performance

The water stress resulted in reduction in sugar and stalk yields and their components like number of millable stalks (NMS), stalk length, and single stalk weight (SSW) and recovery in characters upon release of stress i.e. percent increase in shoot length (PISL) and percent increase in tillers/clump (PITC) (Table 2). There was no effect of water stress on juice quality traits. Reduction in sugar yield under water stress was due to a decrease in stalk yield resulting mainly from reduced NMS and SSW (Table 2). Reduced stalk length was the major cause of reduction in SSW even if there was some improvement in stalk diameter under water stress condition. It was further observed that stalk elongation was higher after release of stress with the onset of monsoon under water stress environment in comparison with normal environment.

Effect of waterlogging on mean performance

The waterlogging stress resulted in increase in component traits like number of millable stalks (NMS) and stalk length and recovery in characters upon release of stress i.e. percent increase in tillers/clump (PITC) (Table 2). There was no effect of waterlogging on sugar yield, stalk yield, single stalk weight (SSW) and juice quality traits. Reduction in stalk diameter under waterlogging stress was compensated by increase in stalk length resulting in similar SSW. Increase in NMS, and similar SSW and juice quality under water logging resulted in similar sugar and stalk yields under normal and waterlogging conditions.

Effect of salinity on mean performance Saline condition resulted in reduction in HR Brix, Pol % (12m) and PISL whereas there was no effect of saline condition on NMS/plot, stalk diameter and stalk length (Table 2). However, there was improvement in SSW resulting in increased sugar and stalk yields. As rains during monsoon season lead to desalinization of soil to varying degrees, depending upon intensity of rainfall and their spatial distribution, the sugarcane growth was improved by such conditions. The tillering, which was low during May – June, increased tremendously after rains resulting in higher PITC. Further, a mixture of salts typical of chloride type soils being used for salinization, Na^{+} and Cl^{-} ions get leached down out of the root zone due to rains / irrigation whereas Ca^{++}, Mg^{++} and SO_4^{-2} ions tend to remain in the root zone which may lead to the observed effect in terms of improved stalk growth of many clones during grand growth period.

Effect of abiotic stresses on important component traits for selection

Effect of abiotic stresses on important traits of stalk and sugar yields in presented in Table 3. The results indicate that in general, clones with higher HR Brix at 8m showed higher pol % at 12m crop age. This indicated that HR Brix at 8-m gives fairly good indication of better juice quality

Table 3. Effect of abiotic stresses on different economic traits of sugarcane

S.No.	Character	Water stress	Water logging	Salinity
1	Sugar yield	Reduced	Reduced	Reduced
2	Stalk yield	Reduced	Reduced	Reduced
3	CCS %	No effect	No effect	No effect
4	Pol % 12m	No effect	Reduced	No effect
5	Pol % 10m	No effect	No effect	No effect
6	Brix % 12m	Increased	Reduced	Reduced
7	Brix % 10m	Increased	Reduced	Reduced
8	Purity % 12m	Reduced	Increased	No effect
9	Purity % 10m	Reduced	Increased	Increased
10	HR Brix 8m	No effect	No effect	No effect
11	Juice extraction %	No effect	Reduced	No effect
12	NMS	Reduced	No effect	Reduced
13	Stalk diameter	Increased	Reduced	Increased
14	Stalk length	Reduced	Increased	No effect
15	SSW	Reduced	Reduced	Increased
16	PISL	Increased	Reduced	Increased
17	PITC	No effect	Increased	Increased

at harvest. This has been supported by highly significant positive correlations amongst these three juice quality traits at 8, 10 and 12m crop age. However, path analysis indicated pol % at 12m as the most important trait of sugar yield where HR Brix and pol % at 10-m contribute towards sugar yield indirectly through pol % at 12m. Pol % at 12m also showed least mean sum of square values due to S x C, E x T, S x T, C x T, and S x C x T (being insignificant) in comparison to HR Brix at 8m. These results indicated that amongst the juice quality traits studied, selection for pol % at 12m would be most effective.

On the contrary, the mean sum of squares for juice quality (T) also decreases gradually from 8 to 12m, which is not a good indication of effective selection. As variability in a particular population is the basis of selection, 8m crop age seems to be the best stage for selecting juice quality traits. However, genotype by environment interaction effects are high for HR Brix at 8m, which is the best stage to isolate early maturing clones. Hence,

Table 4. Genetic stocks for abiotic stresses

Stress	No. of genetic stocks	Name of genetic stocks*
Water Stress, Water Logging & Salinity	4	Co 6806, Dhaur Alig., ISH-007, ISH-135
Water Stress & Water Logging	6	Co 6806, Co 7717, Dhaur Alig., ISH-007, ISH-135, ISH-261
Water Stress & Salinity	6	Co 6806, Co 95021, Dhaur Alig., ISH-007, ISH-135, ISH-148
Water Logging & Salinity	11	Co 6415, Co 6806, Co 87033, Co 93026, Co 97014, Co 98016, CoS 94267, Dhaur Alig., ISH-007, ISH-135, ISH-175
Water Stress	11	Co 6806, Co 7717, Co 95021, Co 97015, Dhaur Alig., ISH-007, ISH-135, ISH-148, ISH-261, ISH-273, Co 1148
Water Logging	16	Co 6415, Co 6806, Co 7717, Co 87033, Co 93026, Co 97014, Co 97017, Co 98016, CoS 94267, BO 91, Dhaur Alig., Pararia Shaj., ISH- 007, ISH-135, ISH-175, ISH-261 Co 6415, Co 6806, Co 87033, Co 89035, Co 93026, Co 95021, Co 97014, Co 97015,
Salinity	18	Co 98015, Co 98016, CoLk 8102, CoS 94267, Dhaur Alig., Pararia Shaj., ISH-007, ISH-135, ISH-148, ISH-175

*Clones with similar performance in different stresses and normal condition.

Table 5. Tolerance to abiotic stresses

Stresses	Superior Clones*
Water Stress & Water Logging	Co 98014
Water Logging & Salinity	Co 97016
Water Stress	Co 98014
Water Logging	Co 97014, Co 97015, Co 97016, Co 98014, Co 98016, CoLk 8102, CoS 94267, BO 91
Salinity	Co 97016

*Significantly superior to Co 1148 on the basis of average of 2 - plant and 1 - ratoon crops

selection for HR Brix at 8m is very important to isolate early maturing clones but for effectiveness of selection the material has to be evaluated over environments / locations to reduce the effect of E x T.

Genetic stocks

Genetic stocks for different abiotic stresses were identified on the basis of their similar performance in stress and normal environments for sugar yield. Four clones, viz. Co 6806, Dhaur Alig., ISH-007 and ISH-135 were identified as genetic stocks for all the three abiotic stresses (Fig. 1). Similarly, six clones for water stress and water logging, 6 for water stress and salinity, 11 for water logging and salinity, 11 for water stress, 16 for water logging and 18 clones for salinity showed similar performance under normal and respective stress environments and hence were identified as genetic stocks for different abiotic stresses (Table 4). These clones could be used as parents in future breeding programmes to incorporate tolerance to various abiotic stresses.

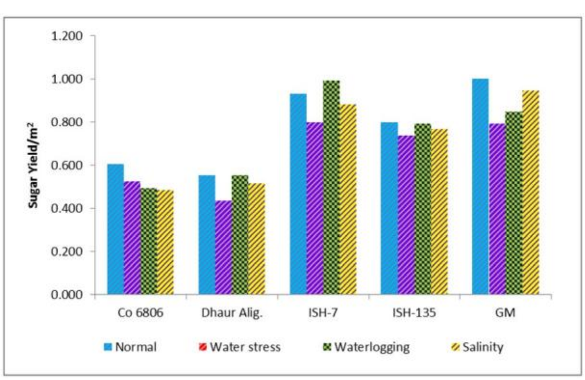

Fig.1. Sugar yield of genetic stocks in comparison with population mean (GM) under different abiotic stresses

Tolerant clones

On the basis of average mean performance of different clones under various stress environments, tolerant clones to different stress environments were identified. Average sugar yield, which depends on both stalk yield and juice quality traits, was taken as the criterion for identifying the tolerant clones. In spite of reduction in sugar yield under stress environments, performance of some clones was significantly better than Co 1148 (standard). None of the clones performed better than Co 1148 under all abiotic stresses. However, Co 98014 performed better both under water stress and water logging whereas Co 97016 was superior under water logging and saline conditions. A list of clones, significantly superior to Co 1148 under different abiotic stresses, is presented in Table 5. These clones could be commercially exploited under their respective problematic

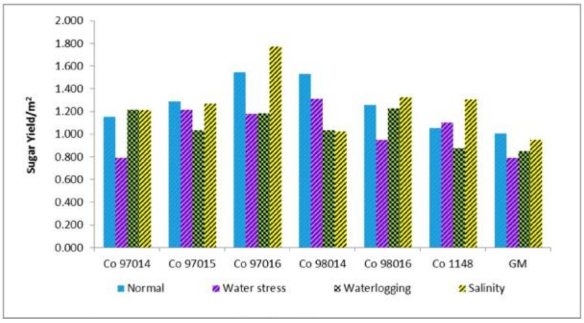

Fig.2. Sugar yield of tolerant clones in comparison with population mean (GM) under different abiotic stresses

environments (Fig. 2). These clones apart from some other clones have been evaluated under normal, water stress and water logging conditions at DSCL Sugars, Ajbapur and under normal and waterlogging conditions at Simbhaoli Sugar Mills Ltd., Simbhaoli. The results obtained at these two sugar mills are in agreement with those recorded at this Centre. Co 97016, Co 98014 and Co 0238 are the best clones, which performed well under abiotic stresses.

Relative response to selection (RR)

Efficient environment, within which a selection should be carried out, can also be judged by relative response (RR) of various traits in different environments. The RR values for different environmental combinations are presented in Table 6. RR values of sugar yield were less than unity, except in case of N vs WS, and N vs WL indicating that selection for sugar yield would be more effective in WLand SS environments whereas in case of N vs WS and N vs WL, selection would be equally effective in any of the environments. Similarly for stalk yield, selection would be more effective if practiced in target environments, except in case of N vs WL environments where selection would be equally effective under both the environments.

Above unity RR values for pol % for N vs WL indicated that selection for pol % would be effective if practiced under N environments. In other cases, the RR values were less than unity and hence indicated that selection would be effective in the target environments. For HR Brix at 8m, RR values were also less than unity in all environmental combinations indicating that selection for HR Brix would be more effective in the target environments.

Near unity RR values for NMS indicated that selection would be equally effective in any of the environments. Selection for stalk diameter would be equally effective in both the environments in N vs WS, WS vs SS and WL vs SS combinations. In rest of the cases, selection for stalk diameter would be effective in target environments. For

Table 6. Relative response to selection between 4 abiotic stresses for ten characters in sugarcane

Environments											
Selection in	**Selection for**	**Sugar yield**	**Stalk yield**	**Pol % (12m)**	**HR Brix (8m)**	**NMS**	**Stalk Diam.**	**Stalk length**	**SSW**	**PISL**	**PITC**
Normal	Water	0.825	0.79	0.716	0.659	0.903	0.815	0.526	0.848	-	0.498
Normal	Waterlogg	0.891	0.86	2.019	0.750	0.903	0.789	0.473	0.891	0.490	-0.126
Normal	Salinity	0.631	0.50	0.762	0.518	0.829	0.769	0.488	0.708	0.365	0.356
Water	Waterlogg	0.782	0.71	0.641	0.724	0.851	0.789	0.701	0.776	0.199	0.137
Water	Salinity	0.694	0.58	0.755	0.756	0.871	0.828	0.724	0.654	0.426	-0.004
Waterlogg	Salinity	0.602	0.57	0.229	0.192	0.875	0.829	0.421	0.625	0.011	-0.162

stalk length, RR values in all the environmental combinations were less than unity indicating that selection would be more effective if practiced in target environments. Near unity RR values were observed for SSW in N vs WS and N vs WL combinations hence selection would be equally effective in both the environments. Rest of the combinations indicated that selection for SSW would be more effective in SS and WL environments. Selection for PISL and PITC would be effective in target environments.

Important traits for selection

The magnitude and direction of correlations and direct and indirect effects varied in different environments. SSW followed by pol % was the most important characters of sugar yield under all conditions. Perusal of inter-environment correlations suggested that sugarcane clones with better stalk yield would produce better sugar yield in any of the environments (Bakshi Ram et al. 2004). Direct selection for NMS, stalk diameter, stalk length, SSW, PITC, HR Brix, pol % and sugar yield would be effective if selection is done in any of the environments as indicated by their significant inter-environment correlation coefficients. However, effectiveness of indirect selection for sugar yield, through its component traits would vary in different environment combinations (Table 7). NMS, stalk diameter and SSW appeared to be the most effective indirect selection criteria for selecting sugarcane clones with high sugar yield under different abiotic stress environments, as indicated by their high inter-environmental correlations. The results also indicated that apart from normal environment, the effectiveness of selection would be more under saline condition followed by water stress and waterlogging conditions.

Unified concept of stress breeding

The efficient environment within which to select can be judged by relative response (RR) of various traits under abiotoc stresses. Relative response

Table 7. Traits for indirect selection for sugar yield under different abiotic stresses

Selection for (Environments)	Normal	Selection under environments		Salinity
		Water stress	Water logging	
Water stress	Stalk length SSW Stalk yield		Stalk length Stalk yield	NMS Stalk length SSW Pol %
Water logging	Stalk length SSW Stalk yield	Stalk length SSW Stalk yield		Stalk yield Stalk length SSW Stalk yield
Salinity	SSW Pol % Stalk yield	Stalk diameter SSW Pol % Stalk	SSW Pol % Stalk yield	

Table 8. Effect of restricted irrigated conditions on mean of progenies of three open crosses

Character	GC-I		GC-II		GC-III	
	NI	RI	NI	RI	NI	RI
NMS/clump	3.59	3.39 (94)	3.73	3.64 (98)	4.04*	3.71 (92)
Stalk diameter	2.00	1.98 (99)	2.00	2.02 (101)	1.95	1.94 (99)
Stalk length (cm)	201.65*	170.55 (85)	207.15*	180.82 (87)	201.20*	172.05
SSW (kg)	0.75*	0.53 (71)	0.71*	0.55 (77)	0.67*	0.52 (78)
Stalk yield (kg)	2.69*	1.89 (70)	2.77*	2.13 (77)	2.78*	2.07 (74)
H.R. Brix	19.46	19.34 (99)	19.49	19.60 (101)	19.26	19.78*
Brix yield (kg)	0.523*	0.359 (69)	0.537*	0.416 (77)	0.536*	0.408

NI: Normal Irrigated; RI: Restricted Irrigated

*Significant differences between two environments at P = 0.05

Figures in parenthesis indicate percentage of corresponding values under NI

values for sugar yield (0.87) and stalk yield (0.867) were the highest in case of water stress vs water logging conditions. However, less than unity RR values for sugar yield and stalk yield indicated that selection for these two traits would be more effective in target environments. Effectiveness of selection for pol % at 12 month would vary in different environmental combinations as indicated by wide variations in RR values. Least variation in RR values was recorded for NMS, stalk diameter and SSW in different environmental combinations. These results indicated that selection in any particular environment for NMS, stalk diameter and SSW would be effective for any of the other environments. NMS and SSW also showed higher GCV, heritability and expected genetic advance values. Hence, NMS and SSW would be most reliable traits for selecting sugarcane clones under abiotic stresses.

Mean sugar yield and stalk yield showed reduction under all abiotic stresses studied (Fig. 3). There was no effect of stress conditions on CCS %, pol % at 10 month, and HR Brix at 8m (Table 3). Pol % at 12 m showed reduction only under water logging condition but CCS % was not affected adversely mainly because of increase in purity % due to forced maturity of stalks. Stalk yield traits showed more variations under different abiotic stresses in comparison with juice quality traits. Hence, selection for juice quality traits would be easier than selection for stalk yield traits under abiotic stresses (Bakshi Ram et al. 2003).

Experiment 2 (Effect of restricted irrigated

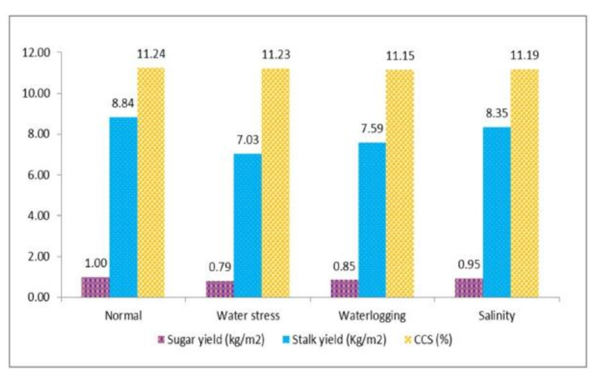

Fig.1. Effect of stress environments on mean performance of sugarcanes clones

Table 9. Mean performance of F_1 progenies under saline conditions of two mating groups of sugarcane

Character	Mating groups		CD (0.05)
	HB	HS	
Stalk yield (kg/plot)	64.60[a]	63.7[a]	4.63
NMS/plot	106.90[a]	130.60[b]	7.54
Sucrose %	16.62[a]	14.87[b]	0.43
Purity %	82.12[a]	78.94[b]	1.23
Stalk diameter (cm)	2.26[a]	1.99[b]	0.07
Stalk length (cm)	146.40[a]	154.90[b]	6.17
Na (mM)	3.42[a]	3.98[b]	0.21
K (mM)	38.09[a]	50.27[b]	2.55
Cl (mM)	71.61[a]	100.21[b]	4.11

HB: Comm. Hybrid x *S. barberi* HS: Comm. Hybrid x *S. spontaneum*

conditions on clones from open crosses)

In another experiment, about 800 clones each from 3 open crosses were evaluated under normal irrigation (NI) and restricted irrigation (RI) conditions. In the trial under RI, two irrigations were skipped from the normal practice of irrigating crops after 10 days during pre-monsoon season. Observations on random 200 clones were recorded to study the effect of RI. The mean performance of 200 clones differed significantly in the two environments (NI & RI) for stalk length, SSW, stalk yield and brix yield in all open crosses, and NMS and HR Brix only in GC-III (Table 8). The maximum reduction under RI was observed in brix yield (31%) in GC-I, SSW, stalk yield and brix yield (23%) in GC-II and in stalk yield (26%) in GC-III (Bakshi Ram et al. 1999). The reduction in SSW was mainly due to reduced stalk length under RI conditions, which resulted in decreased stalk and Brix yields.

Experiment 3 (Evaluation of progenies of *S. barberi* and *S. spontaneum* under saline conditions)

In this experiment 11 progenies each of *S. barberi* (HB) and *S. spontaneum* (HS) crossed with commercial hybrids were evaluated under artificially created salinity condition. HS clones produced more of stalks which were taller, thin types with juice containing lesser sucrose, with lower purity and more of Na, K and Cl in juice than HB clones (Table 9). The effect of higher NMS in HS group was compensated by more stalk diameter in HB group resulting in higher SSW of HB clones (Kumar and Bakshi Ram 1996; Bakshi Ram et al. 1999). Though there were negative correlations between juice quality attributes and K and Cl concentrations but the possibility of selecting genotypes with moderate sucrose % coupled with high stalk yield is not completely ruled out. The clones ISH-135 and ISH-152 showed sucrose % on par, K and Cl concentrations

Table 10. Mean performance of 15 *S. spontaneum* clones under normal and rainfed conditions

Character	Normal	Rainfed
Stalk yield (t/ha)	69.9*	3
NMS (000'/ha)	298*	2
SSW (kg)	0.23*	0.
Stalk diameter (cm)	1.08*	1.
Stalk length (cm)	268*	1
Juice extraction %	23.9	2
Sucrose %	4.06*	3.
Brix %	10.86*	11.83
Purity %	37.18*	29.21

*Significant difference between two environments

higher and stalk yield more than double to that of standard Co 1148. ISH-156 and ISH-175 were two such clones which were found to posses more than 1.5 times higher stalk yields and comparable sucrose % juice and K and Cl concentrations in juice compared to that of standard Co 1148. Intermating amongst ISH-135 and ISH-152 on one hand and ISH-156 and ISH-175 on the other might result in isolation of desirable genotypes for saline conditions with higher stalk yields and good juice quality but with low concentrations of K and Cl in juice.

Experiment 4 (Evaluation of *S. spontaneum* under rainfed (RF)

The mean performance of 15 *S. spontaneum* clones differed significantly in normal and rainfed environments for all the traits except juice extraction %. The maximum reduction of 47% was observed in stalk yield followed by 30% in SSW under rainfed environment (Table 10). The reduction in stalk yield under rainfed was due to decrease in both its components, i.e. NMS and SSW. The decrease in SSW was mainly due to reduced stalk length under RF. Stalk diameter and juice extraction % varied the least in the two environments.Amongst the quality traits, there was reduction in sucrose % and purity % juice under RF whereas about 9% improvement was observed in brix %. Higher brix as compared with normal ones appear to result due to decrease in maturity of canes under RF conditions (Bakshi Ram et al. 1993, Bakshi Ram et al. 1999). Three clones viz, SES-222, SES-275 and SES-352 showed statistically similar performance under the two environments for stalk yield. Their performances were also similar in both the environments with respect to SSW, stalk diameter, juice extraction % and brix % and showed least reduction in stalk length in RF environment.

Experiment 5 (Winter ratoonability)

Genetic improvement for ratoonability under such harsh conditions is much more important in this region than the tropical India. A large number of seedlings and sugarcane clones derived from different categories were evaluated during 2000 – 2006. The sugarcane clones (>7,000), belonging to different categories of germplasm, evaluated at Karnal has showed tremendous genetic variability with respect to ratoonability during winter months. The results obtained have indicated the chances of success in genetic improvement for ratoonability in the sub-tropical region. The improvement in productivity of ratoon crop in this region will tremendously improve its competitiveness with other crops as ratoon crops result in saving of about Rs. 15,000/acre in the cost of cultivation besides better sugar recovery of ratoon crops at early stages. Therefore, it is necessary to combine the resistance/tolerance genes from different sources in the sugarcane clones to identify elite clones with regeneration potential under low temperature conditions of the North Western Zone. Half of plots were ratooned during winter (last week of December) and remaining half plots were ratooned during spring (March). Observations on sprouting %, number of shoots / m and maximum shoot length were recorded after 45 days of ratooning. The salient findings are listed below:

Seedlings of 12 crosses (with more than 500 seedlings) were ratooned during last week of December to observe sprouting during winter months. Observations on sprouting were recorded after 45 days of ratooning. In general, the sprouting during severe winter period was more when both parents of a cross were sub-tropical, followed by crosses with one sub-tropical parent and the least was when both the parents were tropical (Bakshi Ram et al.2005).

Enough genetic variability for better ratoonability during winter season existed in all categories of the material evaluated for selecting elite genetic stocks to be used in further breeding programmes (Sahi et al. 2002).

Mean sprouting % of spring-ratooned clones was better than winter ratooned clones. However, 225 clones when harvested during winter showed better sprouting % than that of spring harvested clones.

Similarly, 75 clones when harvested during winter showed better number of sprouts/m than the mean sprouts/m of spring harvested clones. Similar results were observed for other traits also.

The results indicated the scope for isolating genetic stocks for better ratoonability during winter months. The clones viz. Co 89029, Co 90022, B 256 and IGH 442 were identified as genetic stocks for better ratoonability on the basis of trials conducted at Karnal, Ludhiana and Modipuram.

Utilization of selected clones in future sugarcane breeding programmes is suggested to concentrate the genes for winter ratoonabilty in sugarcane clones suitable for growing in North Western Zone.

Conclusion

Fluctuating climates, which cause water stress, water logging, salinity and cold during winter, limit sugarcane's productivity in sub-tropical region of the country. Therefore, identification of genotypes that impart tolerance to an array of abiotic stresses is warranted to avoid or reduce injury caused by abiotic stresses. Results of a large number of experiments conducted over nine years are compiled in this article. Genetic stocks resistant / tolerant to abiotic stresses like rainfed, water stress, water logging, salinity and low temperature (winter) have been identified. Utilization of these genetic stocks would lead to evolve climate resilient sugarcane varieties in future.

References

Bakshi Ram, Hemaprabha G (1991). Character inter-relationships in cultivar x species progenies in sugarcane. Indian Journal of Genetics, *51*: 89-95.

Bakshi Ram, Kripa Shanker, Sreenivasan, T V (1993) Evaluation of *Saccharum spontaneum* clones under rainfed conditions of north western zone. Indian Journal of Plant Genetic Resources, *6*: 143-149.

Bakshi Ram, Kripa Shanker, Sreenivasan T. V (1995) Effect of rainfed environment on character interrelationships in *Saccharum spontaneum*. Indian Journal of Sugarcane Technology, *10*(1): 10-14.

Bakshi Ram, Hemaprabha G (1997). Correlation and path analysis in interspecific progenies in sugarcane (*Saccharum* spp.). Indian Journal of Agricultural Research, *31*(1): 23-27.

Bakshi Ram, Kumar S, Sahi BK, Tripathi BK (1999). Traits for selecting elite sugarcane clones under water and salt stress conditions. Proceedings of International Society of Sugarcane Technology, *23*: 431-439.

Bakshi Ram, Chaudhary BS, Yadav DK (2000). Effect of visual selection methods on character interrelationships in sugarcane. Indian Journal of Agricultural Research, *34*(1):39-43.

Bakshi Ram, Sreenivasan TV, Sahi BK, Singh, N (2001). Introgression of low temperature tolerance and red rot resistance from *Erianthus* in sugarcane. Euphytica, *122*: 145-153.

Bakshi Ram, Kumar S, Sharma VP, Kumar B (2003). Screening of sugarcane clones for sugar yield and its traits under abiotic stresses. Indian Journal of Sugarcane Technology, *18*: 11-18.

Bakshi Ram, Kumar S, Sharma VP, Kumar B (2004). Traits for selecting better ratooning sugarcane clones under different abiotic stresses. Indian Journal of Sugarcane Technology, *19*: 46-54.

Bakshi Ram, Sahi BK, Hemaprabha G, Kumar P (2005). Effect of ratooning during winter and spring on selection in sugarcane seedlings. Indian Journal of Sugarcane Technology, *20*: 52-56.

Dang YP, Mehla AS, Chhabra R, Kumar S (1998). Sodicity induced yield losses and changes in minerals concentration of sugarcane genotypes. Proceedings of 60th Annual Convention of the Sugar Technologists' Association of India *60*: A123-A135.

Goswami PK, Singh SN (1998) Response of sugarcane genotypes to waterlogging. Indian Sugar *47*: 977-982.

Jackson PA, Hogarth DM (1992) Genotype x environment interactions in sugarcane. I. Patterns of response across sites and crop years in North Queensland. Australian Journal of Agricultural Science. *43*: 1447-59.

James NI (1971) Yield components in random and selected sugarcane populations. Crop Science 11, 906-908.

Johari D, Srivastva RP, Singh SP, Agrawal ML, Singh GP (1998) Effect of moisture stress on growth, yield and juice quality of sugarcane. Cooperative Sugar *30*: 281-282.

Kumar S, Bakshi Ram (1996) Genetic variability, heritability and correlations in hybrid x species progenies of sugarcane grown under saline conditions. Sugar Cane, *1996*(2):

17-19.

Milligan SB, Gravois KA, Bischoff KP, Martin FA (1990) Crop effects on genetic relationships among sugarcane traits. Crop Science *30*, 927-931.

Mirzawan PDN, Cooper M, DeLacy IH, Hogarth DM (1994) Retrospective analysis of the relationship among test environments of the southern Queensland sugarcane breeding programme. Theoritical and Applied Genetics, *88*: 707-716.

Moore PH (1987) Breeding for stress resistance. In: Sugarcane Improvement through Breeding (Ed. D.J. Heinz). Elsevier. pp. 503-542.

Rattey AR, Kimbeng CA (2001). Genotype by environment interactions and resource allocation in final stage selection trials in the Burdekin district. Proceedings of the Aust. Soc. Of Sugar Cane Technol. *23*: 136-141.

Sahi BK, Bakshi Ram, Kumar P (2002) Evaluation of sugarcane clones for ratoonability during winter months. Indian Journal of Sugarcane Technology, *17*(1&2): 1-4.

Singh I, Singh RS, Chauhan RVS, Singh SB (1992) Sugarcane varietal evaluation under rainfed condition. Indian Sugar *42*: 359-362.

Sukhchain, Sandhu D, Saini GS (1997) Inter-relationships among cane yield and commercial cane sugar and their component traits in autumn plant crop of sugarcane. Euphytica 95:109-114.

Received : March, 2017; Revised & Accepted : February, 2018