RESEARCH ARTICLE

G X E INTERACTION STUDIES IN MULTI-LOCATION TRIALS OF SUGARCANE USING GGE BIPLOT AND ANOM ANALYSIS

S. Alarmelu*, R. Balakrishnan and G. Hemaprabha

Abstract

In the process of release of new cultivars using multi-location data, while major emphasis is being laid on superiority of the new cultivars over the ruling cultivars, less importance is being given to genotype × environment (GxE) interaction. The aim of this study was to exploit analysis of genotype and genotype x environment interaction(GGE), its magnitude and significance using analysis of mean (ANOM) which graphically presents the nature of G x E and stability of advanced stage cultivars evaluated in multi-location trials. Data on sucrose, commercial cane sugar %, cane and sugar yields of 14 early clones and three standards from three crops/seasons (2006-2009) and four locations (Coimbatore and Pugalur (Tamil Nadu state), Sankeshwar (Karnataka state) and Padegaon (Maharashtra state) of Peninsular India were analyzed. ANOM studies helped in easy assessment of the sugarcane genotypes for cane yield and sugar yield under four environments and three crop seasons. Significant genotypic differences and G x E interaction influenced the relative ranking of hybrids across environments. ANOM indicated positive interaction effects for cane yield and sugar yield in Co 0209, Co 0312 and Co 0314. GGE (PC1 and PC2) captured 64.0, 60.7, 49.1 and 49.6% of the total variation for sugar yield, cane yield, CCS% and sucrose% respectively. Among the genotypes, Co 0312, Co 0314 and Co 0209 were the top yielders. Co 0312 was identified as the most stable and ideal genotype with high cane and sugar yields, and sucrose % suggesting the potential of this early clone as an alternative to CoC 671. Being the closest to the ideal genotype, Co 0314 was a good candidate when selected specifically for cane and sugar yield. In order to sustain future gains, use of Co 0312 and Co 0314 as alternate checks in clonal evaluation trials is suggested. The high yielding and stable genotypes identified can be exploited as donors in breeding program. The results were compared with two stability assessment methods and the genotypes Co 0312 and Co 0314 with regression coefficient 'b' values near to unity for cane yield and, deviation from regression coefficient (S2d) values of 0.722 and 0.700 respectively were identified stable,in accordancewith ANOM results.

Key words: Sugarcane, genotypes, cane yield, sugar yield, locations, ANOM, stability

Introduction

In breeding programs, desirable genotypes are selected after evaluating many elite genotypes over different locations and seasons. Evaluation of genotypes over a range of environments and years helps to identify either consistently high yielding genotypes across environments or best performing clones at a few environments. Such data collected in multi-location trials are complex in nature and need suitable statistical analysis for accurate interpretation. Many methods,such as variant component, regression approach, Additive Main Effect and Multiplicative Interaction (AMMI) and most recently the Genotype and Genotype × Environment (GGE) have been developed to handle data from multi-location trials. Zobel et al. (1988) compared the traditional statistical analysis, analysis of variance (ANOVA), principle component analysis

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(PCA) and linear regression, with AMMI analyses, and showed that traditional analyses were not always effective in analyzing multiple-environment trial (MET) data structure. The study of genotype x environment (G x E) interaction has been an essential tool in MET because it analyzes the existence of differential behavior of genotypes in different environments.Genotype by environment (G x E) interaction as defined by Baker (1988) is the varied changes in the performance of variety under the influence of varied environmental conditions. Inconsistent genotypic responses to environmental factors such as temperature, soil moisture, soil type, or fertility level from location to location and year to year are a function of G x E interactions. This interaction plays a significant role in the relative expression of yield potential of clones in varied seasons / years and hence identification of yield-contributing traits and knowledge on interactions and yield stability are important for breeding new cultivars with improved adaptation to the environmental stress present in the environments.

GxE practically indicates differential ranking of cultivar performances among environments or seasons and is important only when it is significant and brings about significant change in ranking of genotypes when evaluated in different environments (Kang 1988; Crossa1988).Thus, genotypes which are adaptable to specific environments are selected under an optimum strategy by measuring G x E. Approaches that identify entries showing high performance in both specific and general environments are desirable for G x E quantification. The ANOM method (Nelson et al. 2005) is very similar to ANOVA in concept but more useful in visualization of the main effects and the interaction effects between genotypes and environmentsby indication of the results through control charts with decision lines. It identifies genotypes performing best, poorest and those that are generally stable across the evaluation environments. G x E studies in sugarcane across the globe vary with the selection strategies developed among sugarcane breeding programs and complexity of the different genotypic responses. Climate change predictions indicate that the frequency of dry spell is likely to increase in the future and to mitigate the effects of global climate change, which may result in changes in the performance of sugarcane genotypes, study of G x E interaction is necessary to develop varieties that are adapted to variable environments. The objective of the present study is to determine G x E interactions for sugar yield, cane yield and sucrose % in advanced varietal trials in peninsular zone, with relative importance on testing advanced clones across varied climatic environments and different crop stages.

Materials and methods

In sugarcane, environments comprise locations and years as well as crop type (plant and ratoon). In MET of Peninsular zone, advanced stage trials are planted at several locations and evaluated over several years. Data on ratoon crop is recorded in the same plot of first plant crop to assess ratooning ability. Therefore, the effects of years are complicated as each crop type is grown in different years. Fourteen sugarcane early genotypes, viz. Co 0204, Co 0205, Co 0209, Co 0302, Co 0306, Co 0308, Co 0310, Co 0312, Co 0314, Co 0315, CoM 0254, CoM 9902, CoM 9903 and CoVC 9982, and three early standards (CoC 671, Co 94008 and Co 85004) were evaluated in first plant, second plant and ratoon at four locations, namely Coimbatore, Tamil Nadu state (E1), Padegaon, Maharashtra state (E2), Pugalur, Tamil Nadu state (E3) and Sankeshwar, Karnataka state (E4), during three crop seasons (2008–2010). Experiments were designed as randomized complete blocks with three replications. Each experimental plot consisted of eight rows of

6 m length and row spacing of 90 cm. Normal package of practices was followed during the crop seasons. Data on cane yield, sugar yield, CCS % and pol in juice (sucrose%) at harvest (12 months after planting) were recorded. The variability among the clones in relation to plant type (first plant, second plant and ratoon) and environments (Coimbatore, Padegaon, Pugalur and Sankeshwar) were analyzed through the univariate general linear model. The analysis of means (ANOM) was carried out as detailed by Nelson et al. (2005) to graphically visualize the patterns of variation across environments. GGE biplot analysis was carried out as per the method of Yan and Tinker (2006). Two factor ANOM, the first factor being the entries or genotypes and the second factor being environments (combination of test centers and three crops, namely first plant, second plant and ratoon) was studied and the ANOM charts constructed for entries, environments and their interaction. In this analysis, given *n* locations, we have considered the data as pertaining to 3 x n environments for the MET experiments. In these cases, 2 factor ANOM was performed to bring out the main effects (entries and locations) as well as the interaction effect (Nelson 1988) which helped in visualizing which of the entries had positive interaction at a given test site and which of the entries had a negative interaction. The data were analyzed using Minitab statistical software that has a module for ANOM analysis. In order to compare the evaluation of entries using stability measures and ANOM procedure, pooled data from AICRP variety trials were subjected to Shukla stability variance and stability rankings and Eberhart and Russell (1966) stability parameters. The pooled error mean squares were estimated from the pooled ANOVA and Shukla's stability variance (Shukla1972).

Results and discussion

Analysis of variance

Genotypic difference was found to be significant (P <0.05) for each of the four environments. The differences among the environments were evident between years. The stability analysis indicated the presence of significant G x E interactions for all the characters studied (Table1). Similar trends were

Table 1. ANOVA of G x E interaction studies in multi-location trials of sugarcane

Source	df	MSS			
		Cane yield	CCS yield	CCS%	Sucrose %
Genotypes	16	1062.02 **	32.82 **	3.65 **	7.65 **
Environments	11	37102.40 **	741.07**	167.79 **	211.76 **
G x E	176	530.71 **	12.58**	1.70 **	2.60 **
Block (Env)	24	243.92	17.53	13.23	1.18 **
Error	384	115.27	3.00	0.66	0.9
Total	611				
Grand Mean		112.16	15.37	13.41	18.98
Std Error		10.73	1.73	0.81	0.95
CV%		9.57	11.27	6.03	5.02
LSD (5%)		17.57	2.84	1.32	1.56

ANOM

obtained in MET analysis of genotypes in Peninsular zone (Balakrishnan 2013). Clones interacted with environments and significant differences were shown by the genotypes for sugar yield performance at all the locations (Table 2). Sucrose % was least affected by the crop x environment interaction. Highly significant differences were also shown by varieties in case of pooled analysis of variance (Table 1). Pooled analysis of variance revealed that significant genotypic differences and G x E interaction influenced the relative ranking of hybrids across environments. Environment explained 74.00 % of the total variation, whereas G and GE explained 5.40 and 19.57% of the total variation, respectively for cane yield. GGE (PC1 and PC2) captured 64, 60.7 49.1 and 49.6 % of the total variation for sugar yield, cane yield, CCS % and sucrose% respectively.

Main and interaction effects of clones

The mean cane yield, sugar yield, CCS % and sucrose % of genotypes across all environments are presented in Table 2.

Cane yield: The top five ranked entries for cane yield were Co 0209, Co 0312, Co 0310, Co 0314 and CoM 9902 which recorded significantly higher than the overall mean (112.16 t/ha) across the environments (Table 2). Co 0306 was the lowest yielding type at all locations. Cane yield was significantly ($P \leq 0.05$) higher in Coimbatore and Pugalur (Fig. 1). Co 0209 recorded highest cane yield of 203.8 t/ha in I plant crop at Coimbatore which was higher than the average mean across the environments (Table 3). The second plant and ratoon yields of Co 0209 were also high in this location. The second plant yield of Co 0209 was high in Pugalur. Padegaon recorded the lowest cane yield in first, second and ratoon crops, respectively. The clone performed better in I plant, II plant and ratoon crops at Sankeshwar.

The distribution of the interaction effects was not uniform across the locations and crop stages. The effect of G x E interaction for Co 0209 was significant and positive in the first plant crop at Coimbatore and negative in II plant at Pugalur. The

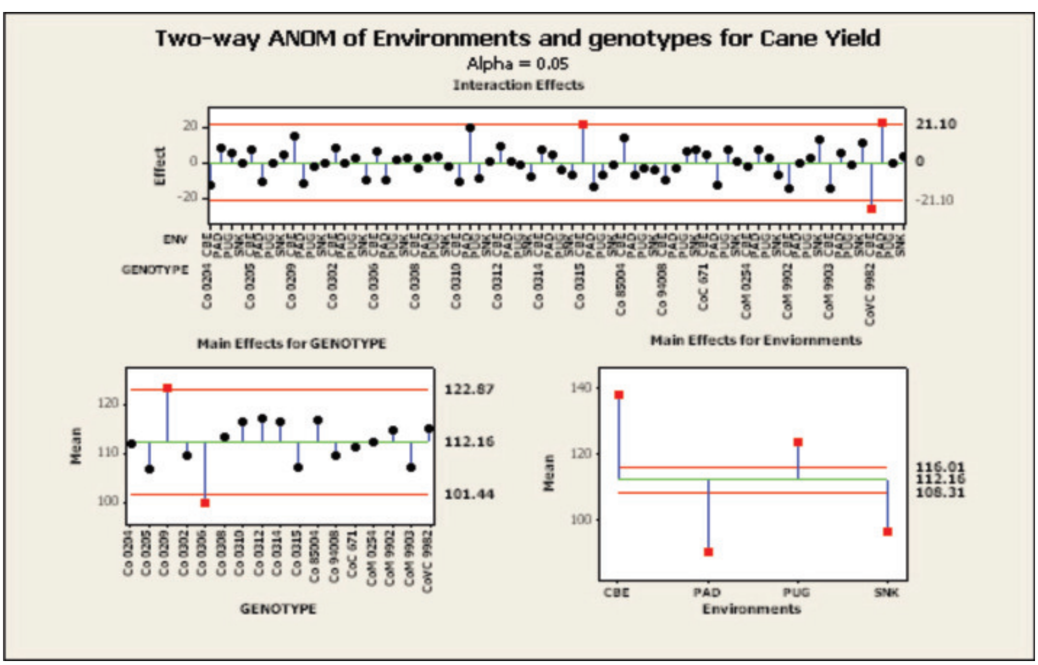

Fig. 1. ANOM of environments and genotypes: cane yield

entries Co 0302, Co 0306, Co 0310, Co 0315, CoM 9902, CoVC 9982 had significant G x E interaction for the trait in the plant and ratoon crops. ANOM indicated significant -ve interaction in Co 0310 (II Plant and ratoon x Coimbatore) and +ve interaction in II Plant x Padegaon. Co 0315 showed +ve interaction in I Plant x Coimbatore and -ve in ratoon x Pugalur. The standards Co 85004 and Co 94008 had +ve interaction in I plant x Coimbatore. CoM 0254 showed +ve interaction in II plant of Padegaon. CoVC 9982 had -ve interaction in I plant x Coimbatore and +ve interaction in II plant at Padegaon. CoC 671 had -ve interaction in ratoon crop of Padegaon. The negative interaction is an indication of low yield which was observed in the genotypes Co 0306, Co 0310 and Co 0315 at Pugalur location in plant and ratoon crop and CoM9902 at Coimbatore in ratoon crop. The positive interaction in our study indicates that the genotypes are high yielders but due to interaction with the environment the yield levels vary in the locations and crop stage. For cane yield, G x E was equally associated with

Table 2. Ranking of early genotypes based on average mean and high mean and stability across environments

Genotype	Cane yield (t/ha)	Rank I*	Rank II**	CCS yield (t/ha)	Rank I	Rank II	CCS (%)	Rank I	Rank II	Sucrose (%)	Rank I	Rank II
Co 0204	111.88	10	9	14.97	12	10	12.90	16	14	18.54	14	14
Co 0205	106.86	16	15	14.98	11	12	13.76	1	5	19.49	3	5
Co 0209	124.92	1	4	17.12	1	3	13.44	10	4	19.02	10	9
Co 0302	109.36	13	10	15.35	8	8	13.55	9	9	19.36	5	3
Co 0306	99.65	17	17	13.80	17	16	13.60	7	3	19.20	7	7
Co 0308	113.24	8	5	14.94	13	11	13.10	13	16	18.61	13	13
Co 0310	116.35	4	6	16.06	5	6	13.67	5	2	19.16	8	6
Co 0312	116.99	2	1	16.63	2	1	13.70	4	8	19.59	1	2
Co 0314	116.25	5	2	16.49	3	2	13.74	3	7	19.53	2	4
Co 0315	107.04	14	16	14.15	15	15	12.97	15	17	18.29	16	17
CoM 0254	112.09	9	7	15.60	7	5	13.75	2	6	19.35	6	8
CoM 9902	115.37	6	8	15.73	6	7	13.57	8	12	19.02	9	12
CoM 9903	106.30	15	14	14.34	14	14	12.97	14	13	18.40	15	15
CoVC 9982	114.98	7	13	15.34	9	13	13.30	12	10	18.70	12	11
Standards												
Co 85004	116.57	3	3	16.31	4	4	13.34	11	11	18.85	11	10
Co 94008	108.80	12	12	14.00	16	17	12.70	17	15	17.86	17	16
CoC 671	111.66	11	11	15.00	10	9	13.66	6	1	19.38	4	1

*Based on average mean; **based on high mean and stability

Table 3. Performance of selected entries across locations and crop years

Entries	I Plant*				II Plant				Ratoon			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
CCS (t/ha)												
Co 0205	24.48	9.98	15.32	12.14	24.42	10.23	16.44	10.83	20.32	9.9	12.7	12.97
Co 0209	29.76	13.21	16.74	14.22	24.38	10.96	18.75	11.95	25.84	10.52	14.74	14.56
Co 0302	28.42	11.81	14.96	10.75	15.29	11.59	16.28	12.05	20.05	10.88	13.9	8.04
Co 0312	24.86	15.02	13.43	11.74	20.75	17.13	19.49	14.11	25.42	13.91	12.62	11.07
Co 0314	24.98	15.9	15.17	11.41	21.23	15.90	17.28	15.36	24.57	13.24	12.41	10.45
Co 0315	26.99	10.22	13.52	8.34	16.23	15.53	14.05	14.01	22.93	6.78	11.21	10.03
Co 85004	27.88	13.43	15.07	11.55	21.25	13.03	17.94	13.75	25.51	12.71	12.49	11.16
Co 94008	17.13	12.50	13.86	13.02	14.32	10.48	17.11	12.66	19.26	9.13	12.94	12.44
CoC 671	25.44	15.71	14.43	12.16	19.12	13.47	18.95	13.24	21.43	7.48	13.68	13.23
CD	3.39	0.15	2.98	NS	5.19	1.70	2.73	1.55	4.88	1.13	2.28	1.93
CV	6.78	0.46	10.03	7.90	8.00	7.37	11.28	8.00	7.89	6.15	10.89	8.40
Cane yield (t/ha)												
Co 0205	164.63	69.16	109.13	90.76	136.17	84.84	142.81	114.27	119.51	69.24	101.73	80.08
Co 0209	203.80	92.16	133.03	107.9	140.12	103.25	161.94	123.00	147.30	74.45	121.47	90.65
Co 0302	185.00	83.46	105.50	77.31	128.89	101.43	151.08	115.29	117.16	76.74	113.13	57.39
Co 0312	163.58	90.88	100.27	88.34	146.79	106.27	179.93	123.51	144.81	90.00	101.50	67.96
Co 0314	161.56	103.50	110.73	89.73	142.59	105.63	154.54	125.25	143.95	87.29	104.63	65.60
Co 0315	190.25	67.57	97.93	89.01	120.74	99.68	137.23	117.55	152.59	48.33	99.94	63.65
Co 85004	171.32	87.69	107.03	89.93	147.90	88.54	164.55	122.17	150.00	87.99	104.63	77.10
Co 94008	134.26	88.57	104.33	100.87	118.77	85.87	167.43	121.15	123.46	70.28	109.26	81.36
CoC 671	175.62	95.83	114.20	95.53	122.22	91.75	170.27	113.86	126.79	49.91	104.51	79.46
CD	17.25	12.32	22.47	NS	27.73	9.39	19.42	9.77	21.1	14.5	17.5	NS
CV	4.64	7.26	8.52	6.60	6.18	6.23	10.68	5.5	5.7	11.2	10.0	9.0

*E1- Coimbatore, E2-Padegaon, E3-Pugalur, E4-Sankeshwar the locations and crop-year. G x E interactions were greater for cane yield than sugar yield and sucrose%, similar to earlier studies (Jackson and Hogarth 1992; Mirzawan et al. 1993). The yields of genotype Co 0209 at Coimbatore in I plant, II plant and ratoon were 203.8, 140.1 and 147.3 t/ha respectively. Smith et al. (2005) in their studies reported that yield and yield traits of sugarcane are highly influenced by environmental factors. Milligan et al. (1990), Jackson et al. (1992) and Jackson and Hogarth (1995) found genotype x location interactions to be of greater importance than genotype x crop-years and genotype x location x crop-years interactions. They suggested testing across several locations to maximize gain and suggested that minimal gains will be achieved from testing multiple crops within a location. Co 0312 ranked second with a mean yield of 116.99 t/ha across environments. The genotype was ranked first based on mean and stability and identified as a stable type. Highest cane yield was observed in all the three crops at Coimbatore. Co 0314 with an average mean yield of 116.25 t/ha ranked second based on high mean and stability criterion. The genotype performed better at Coimbatore, Padegaon and Pugalur. Co 0310, Co 0312 and Co 0314 were identified as stable types for this trait. Co 0209, Co 0312, Co 0310 and Co 0314 had significant yield advantage of 12.48, 5.34, 4.67 and 4.76% respectively over the check CoC 671. These clones were also among the top five ranking in most of the environments (Table 2).

Sugar yield (CCS t/ha): The CCS yield of Co 0209 (17.12 t/ha), Co 0312 (16.63 t/ha) and Co 0314 (16.49 t/ha) (Table 2) were significantly higher and exceeded the overall mean (15.37 t/ha) across the environments and had high stability. These varieties had first three rankings as per high mean and stability. The CCS yield of Co 0306, (13.80 t/ha) and Co 0315 (14.15 t/ha) were significantly lower than the overall mean across all environments and were ranked last as per the high mean and stability criterion. The CCS yield of the check Co 94008 (14.0 t/ha) was below the average mean indicating intermediate stability of the clone for the trait. For some clones there was a change in the performance between crop stages and locations. The clone Co 0315 performed well in Coimbatore in all the three crop stages, I plant crop in Padegaon and first and second plant crop in Sankeshwar. This type of instability justifies our study of G x E in MET. For all three environments, the CCS yield was significantly superior at Coimbatore, but significantly inferior to the overall mean at Sankeshwar (Fig. 2). CCS yield of Co 0209, Co 0312, Co 0314 and Co

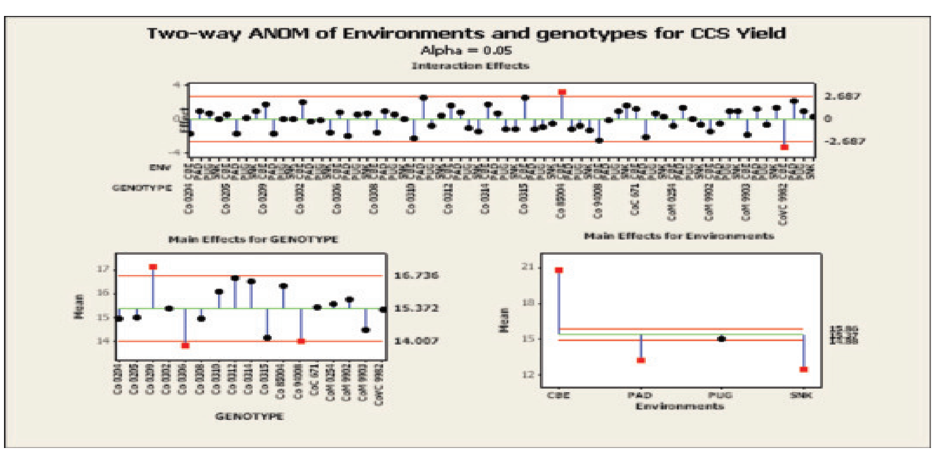

Fig 2. ANOM of environments and genotypes: CCS yield

0315 was significantly superior at Coimbatore. CCS yield of Co 0312 was higher in Coimbatore in first plant (24.86 t/ha), second plant (20.75 t/ha) and ratoon (25.42 t/ha) which were higher than the average mean (Tables 1 and 3). The crop CCS yield for Pugalur was significantly superior whereas its ratoon CCS yield was significantly lower than the overall mean. In Padegaon, the CCS yield for first and ratoon crop was again significantly lower than the overall mean.

ANOM indicated significant positive interaction effects in the genotypes Co 0302 (I Plant x Coimbatore), Co 0310 (I Plant, II Plant x Coimbatore), Co 0315 (I Plant x Coimbatore), Co 85004 (I Plant x Coimbatore), Co 94008 (I Plant x Coimbatore), CoM 0254 (II Plant x Padegaon), CoM 9902 (II Plant x Pugalur), CoVC 9982 (I Plant x Coimbatore). The clones that contributed most to the G x E interaction were Co 0306, CoM 9903 and the check Co 94008.

CCS %: The genotypes Co 0205 (13.76 %), CoM 0254 (13.75%), Co 0314 (13.74%), Co 0312 (13.70%) and Co 0310 (13.67%) were ranked among the top five for CCS % and were significantly higher than the overall CCS % mean (13.41%) across the environments. Co 94008 had the lowest CCS % of 12.70% followed by Co 0315 (12.97%) and Co 0204 (12.90%). The genotypes CoC 671, Co 0310, Co 0306, Co 0209, and Co 0205 had the first five rankings identified as per high mean and stability criterion. CCS % at Coimbatore for the two plant and ratoon crops was significantly superior to the overall mean, whereas for Pugalur and Sankeshwar for all the three crop seasons, it was significantly inferior to the overall mean (Fig.3). The second crop CCS% for Pugalur was significantly superior whereas its first plant and ratoon CCS% was significantly lower than the overall mean. Co 0315 had negative interaction (I Plant x Sankeshwar) for the trait. There was no significant interaction for the trait under other locations.

Sucrose %: Quality was significantly influenced by the environment as compared to quantitative trait in this trial and this may be due to the differential adaptive nature of the genotypes. All the entries under trials at different locations showed significant ($P \leq 0.05$) differences for sucrose %. CoC 671, Co 0312, Co 0302, Co 0314 and Co 0205 ranked among top five and had significantly higher sucrose % values than the overall mean (18.98%) across the environments. The other clones CoM 0254, Co 0306,

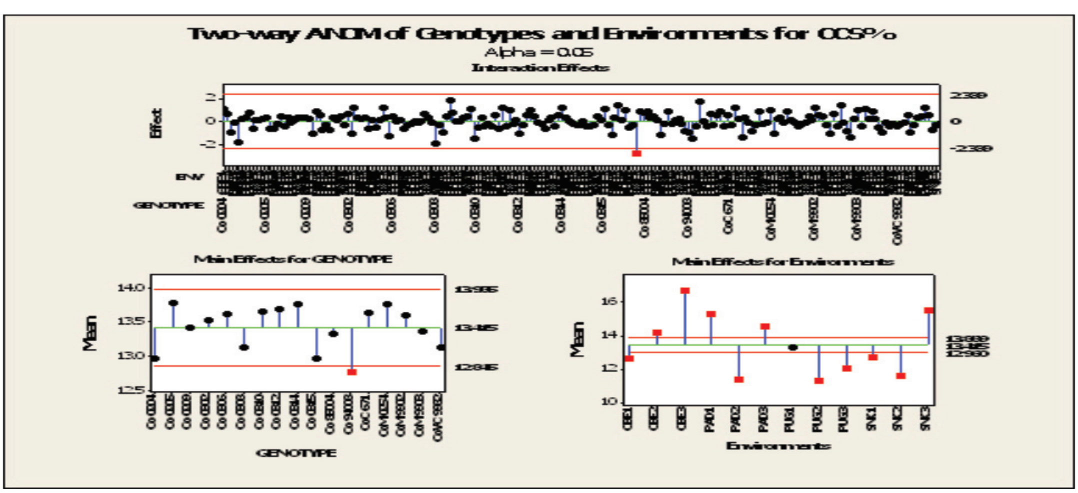

Fig. 3. ANOM of environments and genotypes: CCS %

Co 0310, CoM 9902 and Co 0209 too had significantly higher sucrose than overall mean. Genotype Co 0312 ranked second based on high mean and stability criterion and showed the highest mean sucrose % (19.59%) followed by clone Co 0314 (19.53%) and Co 0205 (19.49%) (Table 2). Co 94008 recorded the lowest sucrose % (17.86%) followed by Co 0315 (18.29%), CoVC 9982 (18.48%) (Table 2). Padegaon recorded highest sucrose % (22.82%) and the lowest was by Sankeshwar (18.80%). Sucrose % at Coimbatore (21.56%) and Padegaon (22.82%) for the two plant and ratoon crops was significantly superior to the overall mean.

The ratoon crop sucrose % for Pugalur was significantly superior whereas that of first plant and second plant was significantly lower than the overall mean. The first plant and second plant crop sucrose % of Sankeshwar was significantly lower than the overall mean (Fig.4).The genotype Co 0315 had negative interaction (I Plant x Sankeshwar) for the trait. Sucrose % at Coimbatore for all three environments was significantly superior to the overall mean, whereas for Sankeshwar and Pugalur for all the three environments, the sucrose % was significantly inferior to the overall mean. ANOM indicated significant interaction effects in the genotypes Co 0204 (-ve in II Plant x Padegaon), Co 0308 (-ve in II Plant x Padegaon), Co 0315 (+ve in II Plant x Padegaon and -ve in I Plant x Sankeshwar), CoM 9902 (+ve in II Plant x Pugalur), Co 94008 (+ve in I Plant x Padegaon) and CoC 671(-ve in I Plant x Padegaon).

Identification of the best genotype in each environment

ANOM indicated positive interaction effects for cane yield and sugar yield in Co 0209, Co 0312 and Co 0314. GGE (PC1 and PC2) captured 64.0, 60.7, 49.1 and 49.6% of the total variation for sugar yield, cane yield, CCS% and sucrose% respectively. Environment explained 74.00% of the total variation, whereas genotype and G x E explained 5.40 and 19.57% of the total variation, respectively for cane yield. Yan et al. (2000) and Yan (2001) indicated in their studies that large positive PC1 scores for genotypes indicate that those genotypes had higher average yield and PC2 scores near zero indicate that those genotypes were more stable. In accordance with this, genotypes Co 0209, Co 0312,

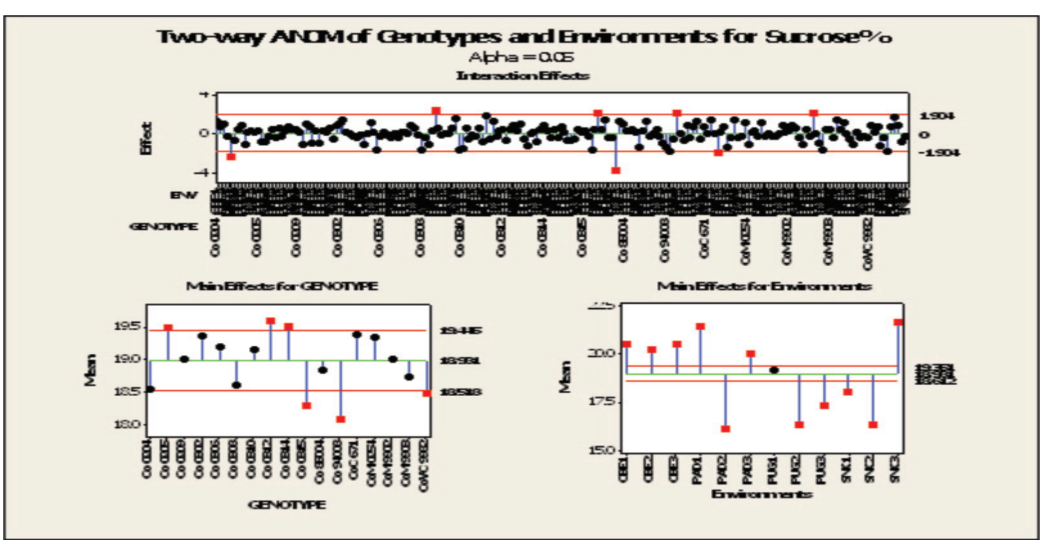

Fig. 4. ANOM of environments and genotypes: Sucrose %

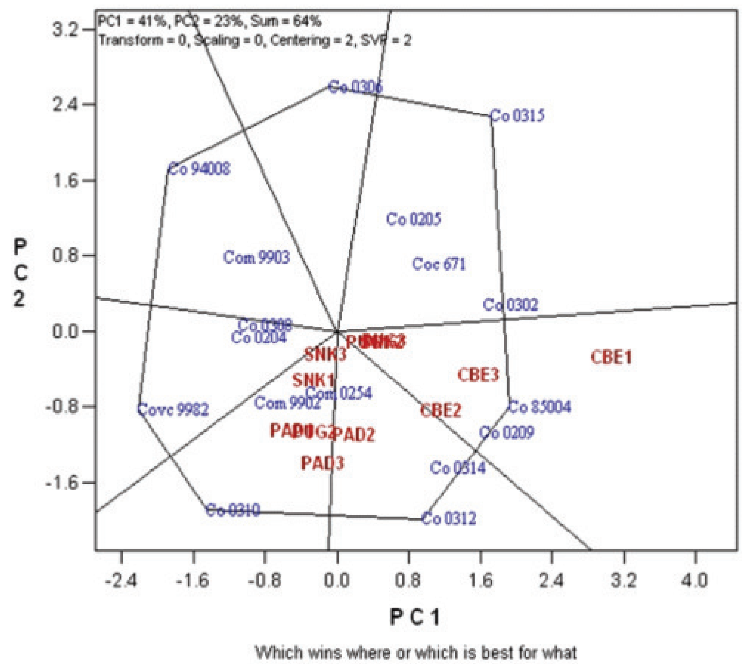

Fig. 5. Best genotypes of sugarcane for different environments based on principal component analysis

Co 0314 and Co 0310 were high yielding genotypes (Fig. 5). On the other hand, genotypes Co 0204, Co 0208, CoVC 9982, Co 94008 and CoM 9903 were with large negative PC1 scores and they were low yielding genotypes (Fig. 5). Genotypes with relatively low PC2 scores such as Co 0312, Co 0314 and Co 0209 can be considered relatively stable. The environments with large PC1 scores are those that better discriminate among genotypes and those with PC2 scores near zero are more representative of an average environment (Yan et al. 2000; Yan 2001). In this study, almost all the environments had larger PC1 scores and well discriminated among the genotypes.

According to Yan et al. (2000) and Yan (2001), genotypes at the apex of each sector are the best performing at environments included in that sector if the GGE is sufficiently approximated by PC1 and PC2. PC1 and PC2 accounted for 64% of the total PCs showing that they had sufficiently explained the GGE. Specific adaptation of clones Co 0312, Co 0314, Co 0209 and Co 0302 was observed at Coimbatore and Padegaon, while clones Co 0310, CoM 9902 and CoM 0254 were well adapted at Pugalur, Padegaon and Sankeshwar. These clones can be identified as location specific genotypes.

Stability studies

Eberhart model detected three clones, viz. Co 0312, Co 0314 and Co 0209 as stable for cane and sugar yield. The results from Shukla method also confirmed these clones to be stable. The ‘b’ value being greater than 1.00 for cane yield, sugar yield and sucrose % for Co 0312 and Co 0314 indicated their potential to take advantage under favourable environments. Accordingly, Co 0312 and Co 0314 with regression coefficient ‘b’ values near to unity for cane yield and,deviation from regression coefficient ‘S2d’ values of 0.722 and 0.700 respectively were identified stable. This was in confirmation with visualization of ANOM in our study.

Conclusion

Sugarcane clones in Peninsular zone were evaluated in a wide range of environments for cane yield and sugar yield. The outcome is always affected by G x E interaction which is commonly observed as the differential ranking of the genotypes across the locations or seasons. In the present study, variation in locations manifested in performance of the genotypes. This interaction may be either a cross over G x E interaction or non-cross over in nature. According to crossover nature, performance from one environment to another is the significant change (Matus et al. 1997). The behavior may be cross over in which significant change in ranking order occurs from one environment to another or non-cross over nature in which the ranking of genotypes remains constant across environments and the interaction is significant because of change in the magnitude of response depending upon the ranking order of genotypes performance under different environments (Baker1988). An appreciable amount of G x E interactions was observed in this study. The response of the genotypes to the changing environments is best characterized by G x E. ANOM studies helped in easy assessment of the sugarcane genotypes for cane yield and sugar yield under four environments and three crop seasons and according to ANOM, the G x E that tends to be close to the origin of biplot were stable and farther ones are those that interact with environment. It is useful to determine the performance of a genotype in a specific environment, compare performances of genotypes across environmentsand identify high yielding varieties across environments. It has been utilized in quantifying the performance of sugarcane clones under abiotic stresses and clones with better adaptability were identified under different abiotic stress conditions (Bakshi Ram et al. 2013).

In general, large PCA 1 and small PCA 2 would be more useful for genotype discrimination. In our study, Co 0310 and CoVC 9982 had large negative PCA showing specific adaptation to Padegaon, where they performed well. The varied response of the genotypes may be due to prevalence of high stress factors in these centers. The G x E interaction was associated with remarkable changes in the relative ranking of genotypes across environments, even among the top performing genotypes. Differences in ranking of genotypes across environments indicated the presence of genotype x environment interaction and the genotypes Co 0209, Co 0312 and Co 0314 appeared in the top five ranks of the three crop seasons in all the environments and can be identified as stable and adaptive genotypes. Among them, Co 0312 was identified as the most phenotypically stable and ideal genotype with high cane and sugar yield, and sucrose %, and general adaptability in plant and ratoon crop suggesting the potential of this early variety for Peninsular zone as an alternative to CoC 671. Co 0314 was the closest to the ideal genotype and a good candidate when selected specifically for cane and sugar yield. Co 0209, Co 0312, Co 0314 also performed better and exhibited their superiority in initial varietal trial across the different centers of Peninsular zone for cane yield and sugar yield. The high yielding and stable genotypes identified can be exploited as donors to identify stable progenies for further use in breeding programmes.

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