Research Article

Evaluation of Sugarcane Genotypes for Different Ecologies of Pakistan by Employing Gge-Biplot Technique

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Abstract | The aim of this study was to identify sugarcane (*Saccharum officinarum* L) genotypes that combine high yield and stability across environments via Genotype and Genotype × Environment (GGE)-Biplot Technique to identify best potential varieties of sugarcane for a region. Nineteen varieties of sugarcane were assessed in seven environmentally different locations of Pakistan for their yield response. Experiment at each location was carried out in randomized complete block design (RCBD) with three replications. The environment (E) explained 16.1% of the total variation whereas G and G × E interaction captured 48.2 and 34.5 %, respectively. The GGE-Biplot grouped the locations into two mega and two minor environments and indicated best performing genotype for each. Hence the GGE-Biplot ranked HoTh-300 (V-15) and LRK-2004 (V-9) varieties as the best performer across locations followed by CP-NIA-82-223 (V-12), HoTh-127 (V-14) and HoTh-326 (V-16) varieties while based upon both high yielding ability and stability of performance. It also indicated Larkana environment as the ideal location, most discriminating for varieties with the greatest G × E interaction and representative for all other locations. Hence GGE-biplot analysis tool can be applied facilitate evaluation of superior sugarcane varieties for different agro-ecologies.

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Keywords | GGE Biplot, Sugarcane genotypes, Stability performance, Larkana, Sugarcane yield

Introduction

Sugarcane (*Saccharum officinarum* L.) is an important cash and sugar crop in Pakistan. It is being grown on an area of about 1.31 million hectares with a total production of 81.44 million tons (Jamshaid, 2017) ranking 5th in the world. However, the per acre sugarcane yield in Pakistan (62.2 ton ha^{-1}) is far less than the varietal potential yield (100-150 ton ha^{-1}) as well as sugarcane yield in significant cane growing countries and world average yield of 70.6 ton ha^{-1} (FAO, 2018). This is due to lack of proper climate resilient varietal selection along with many other agro-technological reasons.

In Pakistan, sugarcane is grown in the areas ranging from costal hot humid in the southern Sindh to very hot dry in upper Sindh and southern parts of Punjab as well as frosty cool climate of parts of Punjab and KP. Hence sugarcane growing regions of Pakistan vary climatologically and crop has to withstand the severity of the climate in the country. It necessitates developing and identifying specific varieties for each region.

Links Researchers

Genotype × Environment interaction (GEI) is an important aspect of plant breeding programs. It may arise when certain genotypes are grown in diverse set of environments. A significant G × E interaction for a quantitative trait such as yield can seriously limit the efforts on selecting superior genotypes for both crop production and improved cultivar development (Kang and Gorman, 1989). By growing cultivars in different environments, the highest yielding and most stable cultivars can be identified (Lu'quez et al., 2002; Farshadfar et al., 2012; Akhter et al., 2015). When selecting genotypes for wide adaptation, plant breeders look for a non-crossover GEI or preferably the absence of GEI (Matus-Ca´diz et al., 2003). Thus, the estimation of stability of performance becomes important to identify consistent performing and high-yielding genotypes (Kang, 1998). Different researchers have used different stability statistics to determine whether or not cultivars evaluated in multi-environment yield trials (MET) are stable (Zubair and Ghafoor, 2001; Sabaghnia et al., 2006; Luo et al., 2012). Because the most stable genotype(s) may not be the highest yielding, the use of methods that integrate yield performance and stability to select superior genotypes becomes important (Kang and Magari, 1996; Luo et al., 2015).

The conventional method of partitioning for variety × environment interaction conveys little information on the individual patterns of response (Kempton, 1984) and are being covered by regression analysis (Gauch, 1988), multivariate analysis (Westcoff, 1987), cluster analysis (Crossa et al., 1991). In recent time additive main effect and multiplicative interaction (AMMI) model is also being used (Rea et al., 2011; Ready et al., 2011). Recently GGE Biplot Analysis is used (Yan 1999; Luo et al., 2012; Akhtar et al., 2015). Yan (1999) and Yan et al. (2000) proposed that GGE biplot allowed visual examination of the GE interaction pattern of MET data emphasizing two concepts viz., genotype by environment interaction (GE) and biplot technique developed by Gabriel (1971) employed to approximate and display the GGE of a MET. In addition, the GGE biplot also has a usage in selecting superior genotypes and test environments for a given mega-environment.

The objectives of this study were to investigate the stability in yield performance of sugarcane genotypes using GGE-biplot technique tested under diverse environmental conditions of Pakistan.

Materials and Methods

Nineteen sugarcane candidate varieties, contributed by eight different institutes were used in this investigation (Table 1). Seven locations were selected in the Punjab, Sindh and Khyber Pakhtunkhwa sugarcane growing regions which were diverse in agro-climatic conditions (Table 2). At each location, a randomized complete block design with three replications was employed for the trial conducted.

Table 1: *Sugarcane varieties name, code name and contributing institutes.*

Code	Candidate variety	Contributing Institute
V-1	CP-85-1491	Sugar Crops Research Institute, Mardan
V-2	CP-80-1827	Sugar Crop Research Institute, Mardan
V-3	S2002-US-560	Sugarcane Research Institute, Faisalabad
V-4	S2002-US-637	Sugarcane Research Institute, Faisalabad
V-5	S2002-US-640	Sugarcane Research Institute, Faisalabad
V-6	S2000-CPSG-449	Shakarganj Sugar Research Institute, Jhang
V-7	S2000-CPSG-1550	Shakarganj Sugar Research Institute, Jhang
V-8	LRK-2003	Qaid-e-Awam Agricultural Research Institute, Larkana
V-9	LRK-2004	Qaid-e-Awam Agricultural Research Institute, Larkana
V-10	Ganj Bakhash	Qaid-e-Awam Agricultural Research Institute, Larkana
V-11	GT-11	Agricultural Research Institute, Tandojam
V-12	CP NIA-82-223	Nuclear Institute for Agriculture, Tabdojam
V-13	CP NIA-82-1026 SC-P5	Nuclear Institute for Agriculture, Tabdojam
V-14	HoTh-127	National Sugar Crops Research Institute, Thatta
V-15	HoTh-300	National Sugar Crops Research Institute, Thatta
V-16	HoTh-326	National Sugar Crops Research Institute, Thatta
V-17	CPD-01-245	Dewan Farooq Sugar Research Institute, Thatta
V-18	CPD-01-354	Dewan Farooq Sugar Research Institute, Thatta
V-19	CPD-01-335	Dewan Farooq Sugar Research Institute, Thatta

Table 2: *Latitude, longitude, altitude and soil type of the experimental locations during 2007-08.*

Location	Code	Latitude	Longi-tude	Alti-tude	Soil Type
Islamabad	ISL	33° 40' N	73° 10' E	540 m	Silty clay loam
Tandojam	TJM	25° 25' N	68° 31' E	23 m	Silty clay loam
D. I. Khan	DIK	31° 83' N	70° 91' E	175 m	Sandy loam
Faisalabad	FSD	31° 42' N	73° 05' E	184 m	Silty loam
Thatta	THT	24° 44' N	67° 58' E	8 m	Sandy loam
Larkana	LRK	27° 56' N	68° 21' E	135 m	Silty loam
Jhang	JNG	31° 17' N	72° 19' E	158 m	Sandy loam

Three budded sugarcane stalk setts were planted @ 55,000 setts ha^{-1} in each plot. Each plot consisted of four rows having eight-meter length and 4.8 m width and cultivated with furrows at 1.2 m apart. The sugarcane setts were placed in double rows at 10 cm gap with joining ends in each furrow and covered with about two cm soil layer after application of 1/3rd of nitrogen and entire Phosphorus and Potash fertilizers. Fertilizers were used in the form of Urea, diammonium phosphate (DAP) and sulphate of potash (SoP) at 250, 140 and 150 kg ha^{-1} for N, P_2O_5 and K_2O, respectively. Weeds were initially controlled with application of herbicide Amatrine + Atrazin (80 WP) @ of 3.75 kg ha^{-1} while at later stages, weeding was carried out manually when needed. Irrigations were made according to the environmental conditions that ranged from 16 to 22 at different locations. Other field management practices were uniform and standard across locations.

The crop was grown for fourteen months' period and then harvested for data collection. For this purpose, an area of 4.8 m^2 was harvested from each plot at the soil surface, detrashed and removed the top green leaves at the zenith 2nd or 3rd internode. Then the cleaned canes were weighed to estimate cane yield in tons per hectare.

The cane yield data was subjected to Analysis of Variance (ANOVA) technique (Steel and Torrie, 1980) to find out whether genotype × environment interaction was significant or not, thereafter the GGE-biplot method (Yan et al., 2000) was employed to study the stability of genotype with different sites for cane yield. The evaluation based on the model: *yij – yj = y1εi1pj1 + y2εi2pj2*, where: *yij* is the average yield of ith population in jth environment; yi is the overall mean of population j in environment j; *y1εi1pj1* is the first principal component (PC-1); y2εi2pj2 is the second major component (PC-2); y1, y2 are the eigenvalues associated to PC-1 and PC-2, ε1 and ε2 are the scores of 1st and 2nd main component of the ith population and pj1 and pj2 are the scores of the 1st and 2nd principal component for the jth environment, respectively; and εij is the error associated with the model of the ith population and jth environment (Yan and Kang, 2003; Mattos et al., 2013).

Results and Discussion

Results from the analysis of variance showed that both the main effects i.e. genotype (G) and location/ environment (E) and their interaction effect (G × E) had a significant influence on cane yield (Table 3). The relative magnitude of the variance explained by G, E and G × E is also shown in Table 3. The variation due to E was responsible for 16.1 % of the variance, while the variation due to G was 48.2 %. The variation due to G × E interaction had a contribution of 34.5 % to the total variation which is an indication of possible existence of differences among the locations in which the sugarcane varieties were evaluated. Zobel et al. (1988) and Mattos et al. (2013) reported that in multi-locational trials, the environment (E) normally explains up to 80% of the variation while G and G × E both usually represent around 10-20 % of each variation. Likewise, Luo et al. (2015) reported about 40% impact on cane yield only due to environment. However, in present study variations due to G and G × E is more suggesting that genotypes may be selected for specific environments as have been reported by other researchers (Xu et al., 2014; Akhter et al., 2015). Analysis of Variance (ANOVA) also represented that G × E interactions were significant for yield response. The results also indicated that the genotypes can be characterized for environmentally induced variations (Mattos et al., 2013; Luo et al., 2015). The mean cane yield of different sugarcane varieties across various locations is shown in Table 5. Among the locations maximum cane yield (119 ton ha^{-1}) was attained at LRK (Larkana) followed by ISL (Islamabad) (97 ton ha^{-1}), while minimum cane yield of 74 ton ha^{-1} was noticed at DIK (D.I. Khan). Across locations cane variety LRK-2004 (V-9) outclassed all other varieties by producing cane yield of 111 ton ha^{-1}, followed by CPD-01-335 (V-19) with an average cane yield of 108 ton ha^{-1}, while minimum cane yield of 81 ton ha^{-1} was produced by cane varieties S2002-US-560 (V-3) and GT-11 (V-11).

Table 3: *ANOVA for sugarcane yield data (ton ha^{-1}) obtained from sugarcane varietal trial at seven locations/ environments.*

Sources of variances	Degrees of freedom	SS	MS	% Sum of square
Reps with in E	14	4658.8	332.8**	--
Environment (E)	6	65164.2	10860.7**	16.1
Genotypes (G)	18	195492.2	10860.7**	48.2
G × E	108	140065.2	1296.9**	34.5
Error	252	329.1	1.3	--
Total	398	405709.5		
CV =1.23 %				

*** Significant at 0.01 % level of probability.*

The adaptability and stability of sugarcane genotypes can be graphically interpreted considering biplots with the first two axis of G × E interaction (Mattos et al., 2013). Hence yield performance of 19 sugarcane varieties is shown in the biplot across seven locations (Figure 1). These seven locations were distributed in four sectors. The first sector contained LRK (Larkana), FSD (Faisalabad) and DIK (D.I. Khan); the second sector had THT (Thatta). The third sector contained ISL and TJM (Tandojam), while the fourth sector had only JNG (Jhang). Figure 1 of GGA biplot represents a polygon view that is important to study the possible existence of mega environments within a growing region (Yan and Rajcon, 2002; Mattos et al., 2013; Xu et al., 2014). In this case two mega environments are Mega-I comprising Larkan, D.I. Khan and Faisalabad and Mega-II consisted of Islamabad and Tandojam. The other two minor environments were Thatta and Jhang. The polygon also indicated some varieties on the vertices while the rest on the inside of the polygon. These vertex varieties are the most responsive varieties since they have the longest distance from the biplot origin and best average performance in one or all environments (Yan and Rajcan, 2002; Luo et al., 2015). In the first sector the vertex varieties V-9 and V-15 were the best at both Larkana and Faisalabad locations. In the same sector sugarcane varieties V-12 and V-16 also performed well at all the three locations i.e. Larkana, Faisalabad and D.I. Khan. In the third sector V-19 was best at Islamabad and Tandojam locations. Sugarcane variety V-3 is supposed to be the best at Jhang as it is the vertex variety in sector four. Since, vertex 2 occupied no sugarcane variety therefore it is concluded that no variety performed the best at Thatta.

Table 4: *Overall mean, GGE distance of sugarcane varieties from "ideal" variety and ranking (via GGE-biplot) on both average yield and stability performance across seven environments.*

Code	Varieties	Overall mean	GGE rank	GGE distance
V-1	CP-85-1491	85	10	9.3
V-2	CP-80-1827	88	7	8.1
V-3	S2002-US-560	81	19	13.5
V-4	S2002-US-637	97	15	10.5
V-5	S2002-US-640	83	17	11.7
V-6	S2000-CPSG-449	90	11	9.3
V-7	S2000-CPSG-1550	84	13	9.7
V-8	LRK-2003	89	18	11.8
V-9	LRK-2004	111	2	4.7
V-10	Ganj Bakhash	86	14	10.1
V-11	GT-11	81	16	10.8
V-12	CP NIA-82-223	98	3	6.4
V-13	CP NIA-82-1026 SC-P5	94	9	9.0
V-14	HoTH-127	91	4	6.8
V-15	HoTH-300	104	1	1.2
V-16	HoTH-326	99	5	7.5
V-17	CPD-01-245	100	6	7.8
V-18	CPD-01-354	94	8	8.8
V-19	CPD-01-335	108	12	9.6

Figure 2 and 3 represents to the average yield and stability performance of 19 sugarcane varieties evaluated at seven locations. The average yield of varieties is approximated by the projection of their markers to the ATC X-axis (the single arrowed line; the direction indicates the positive end) while the stability of the varieties is approximated by the projection of their markers to the ATC Y-axis (double arrowed line) (Yan, 2001). The GGE identified V-15 as highest yielding variety, followed by V-9 and V-19 while V-3 as the poorest yielding variety. For only stability of performance V-15 was the best among all varieties followed by V-16 and V-12. However, varieties with high cane yield and relatively stable performance are important for growers. An "ideal" genotype is one that is the highest yielding (longest projection on ATC X-axis) across test environments and is absolutely stable (Shortest projection on ATC Y-axis) in performance (i.e., one that ranks the highest in all test environments) (Yan and Kang, 2003; Fan et al., 2007). When an "ideal" genotype view was drawn, sugarcane variety V-15 (GGE distance 1.2) was the closest to "ideal" variety

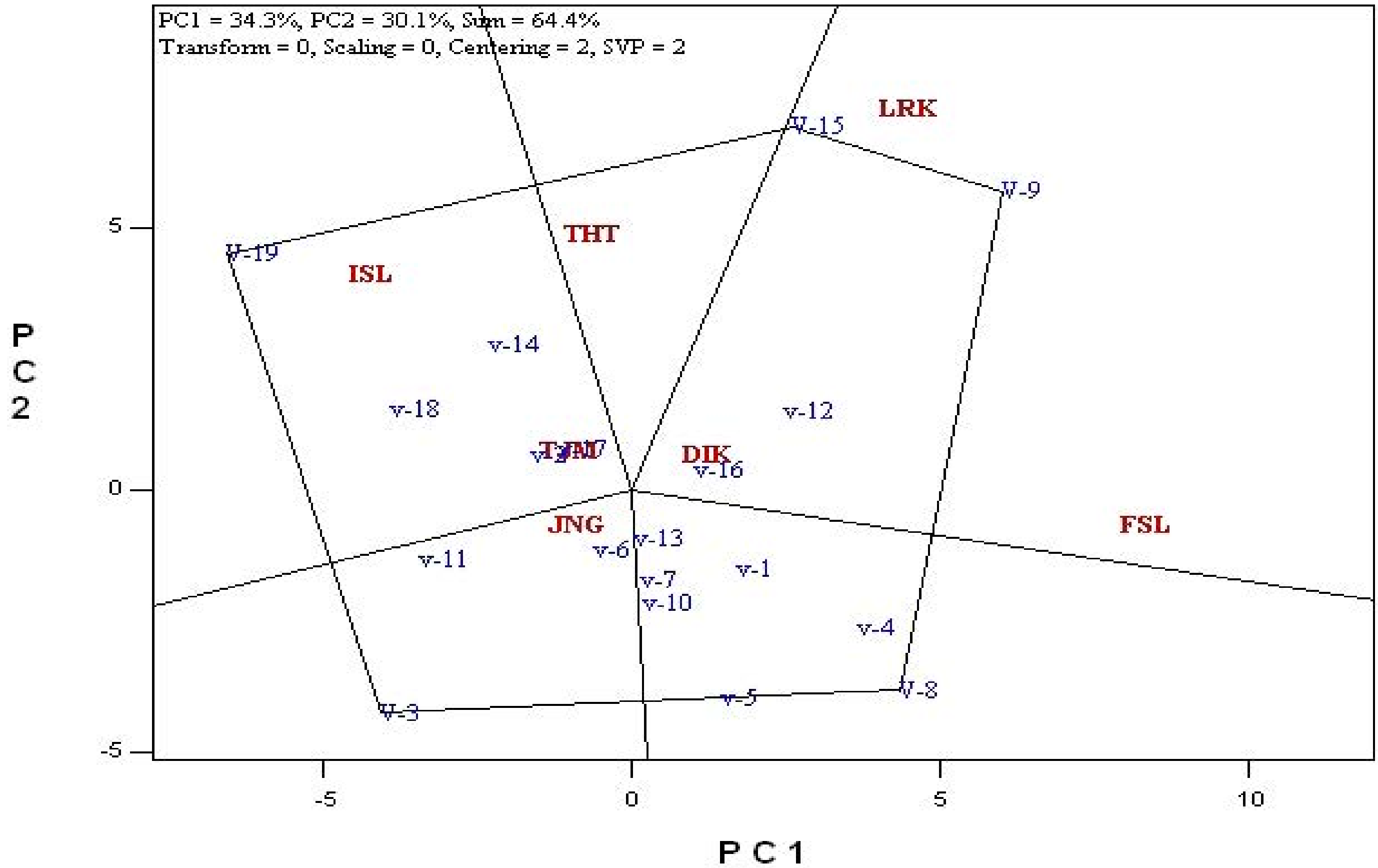

Figure 1: *Yield performance of 19 sugarcane varieties across seven locations/environments (E) in Pakistan. FSL= Faisalabad; DIK= D.I. Khan; LRK= Larkana; THT= Thatta; ISL= Islamabad; TJM= Tandojam; JNG= Jhang. PC1 and PC2 are the first and second principal components respectively.*

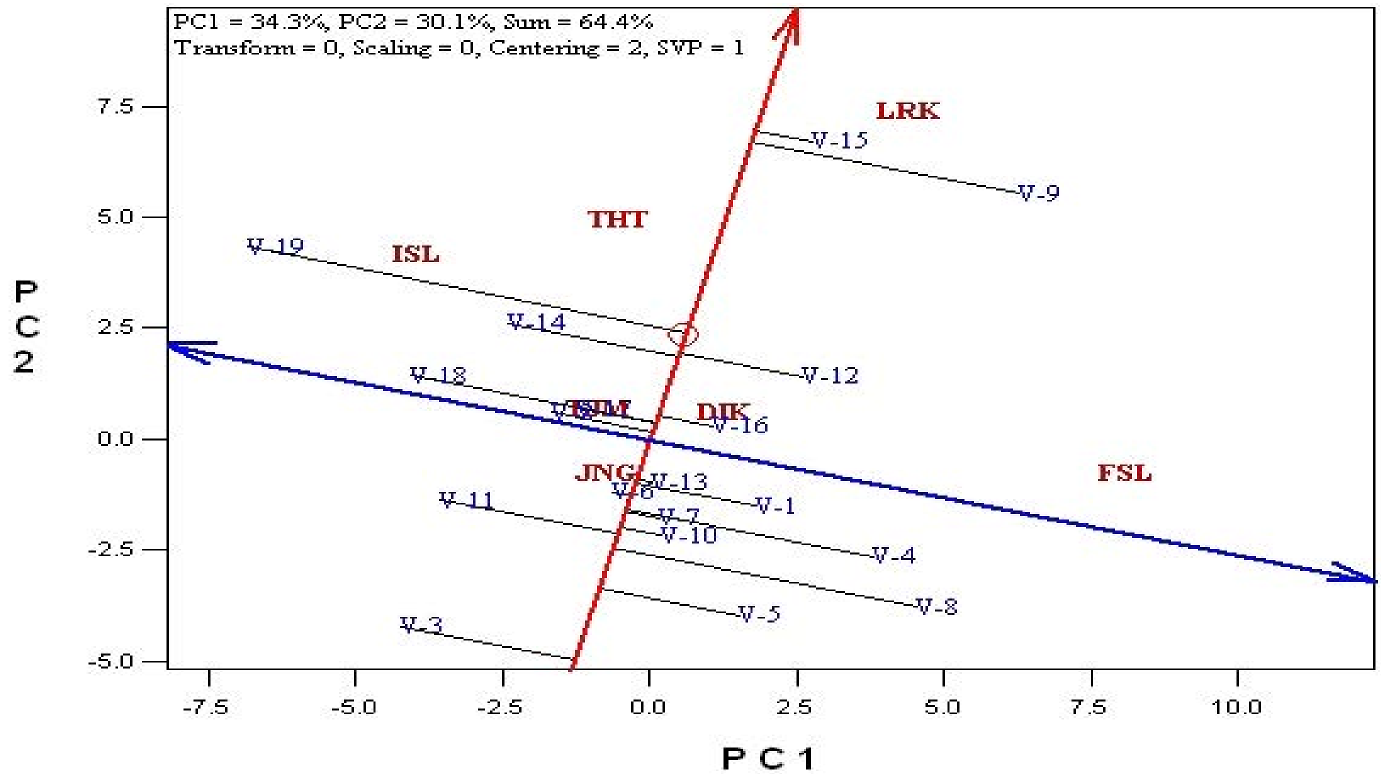

Figure 2: *Biplot showing average yield and stability of sugarcane varieties.*

(center of the concentric circle) and supposed to be the best among all on the basis of average yield and stability of performance (Figure 3 and Table 4). Sugarcane varieties can be ranked on the basis of cane

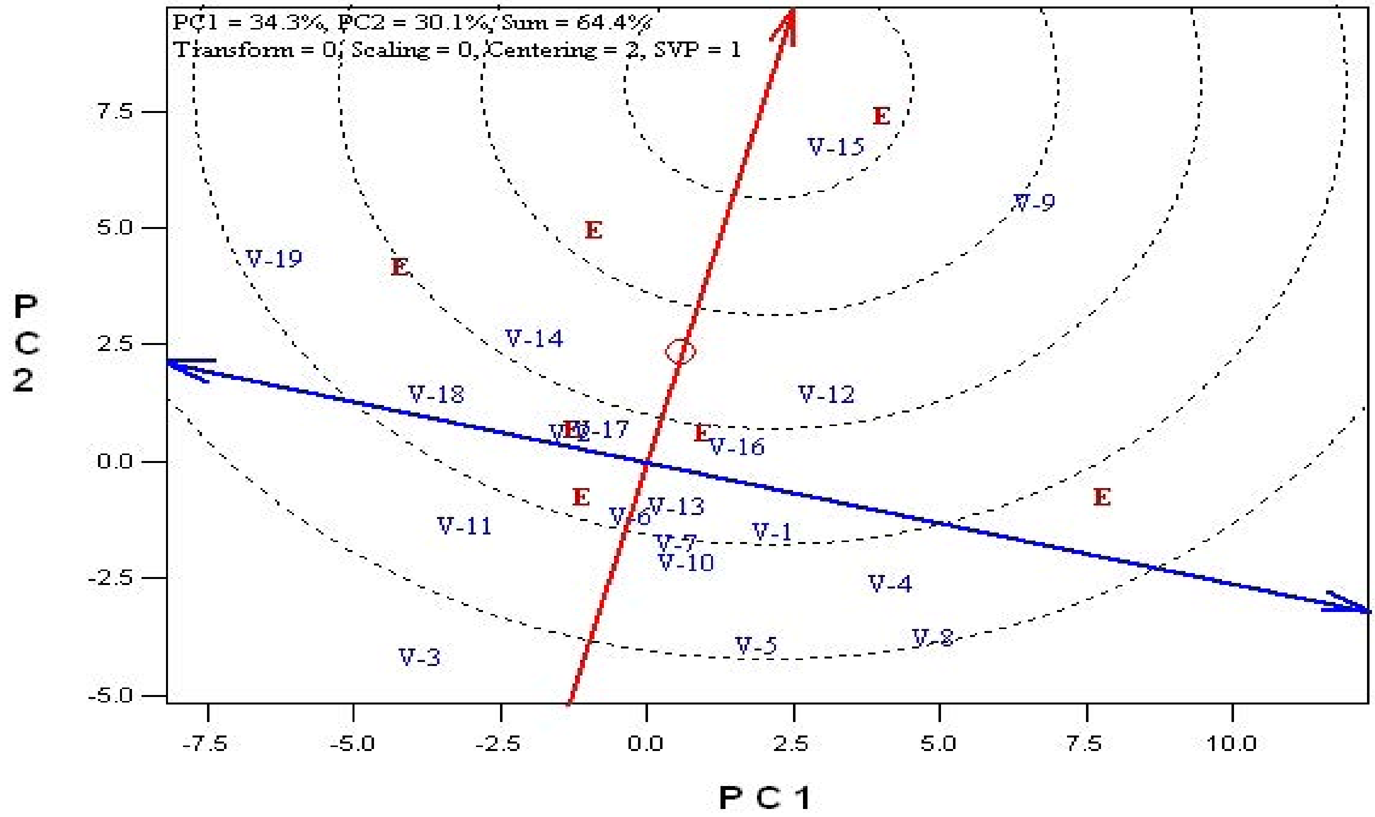

Figure 3: *Ranking of sugarcane varieties by comparing them with an "ideal" variety.*

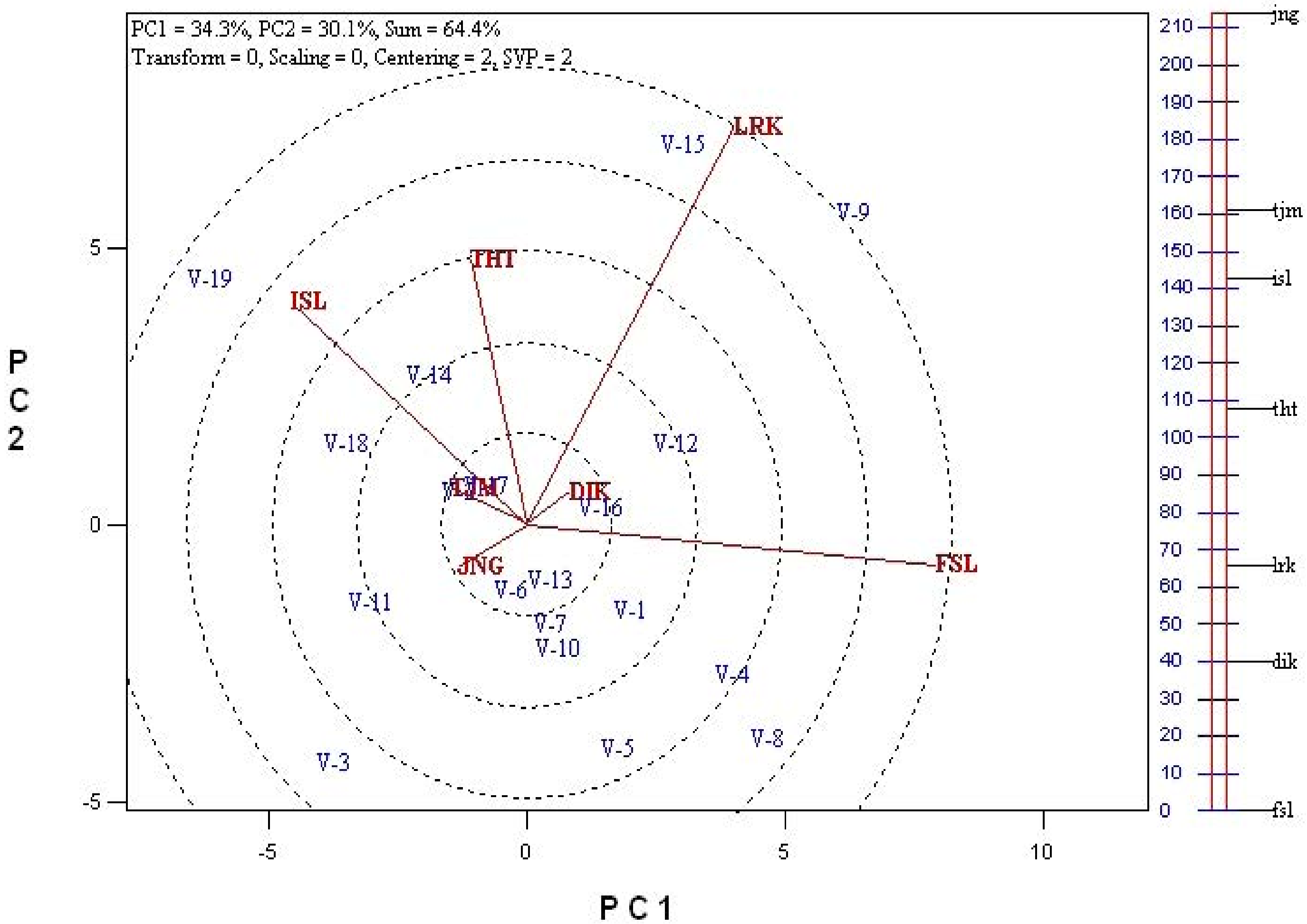

Figure 4: *Biplot showing relationship among seven locations/ Environrmnts.*

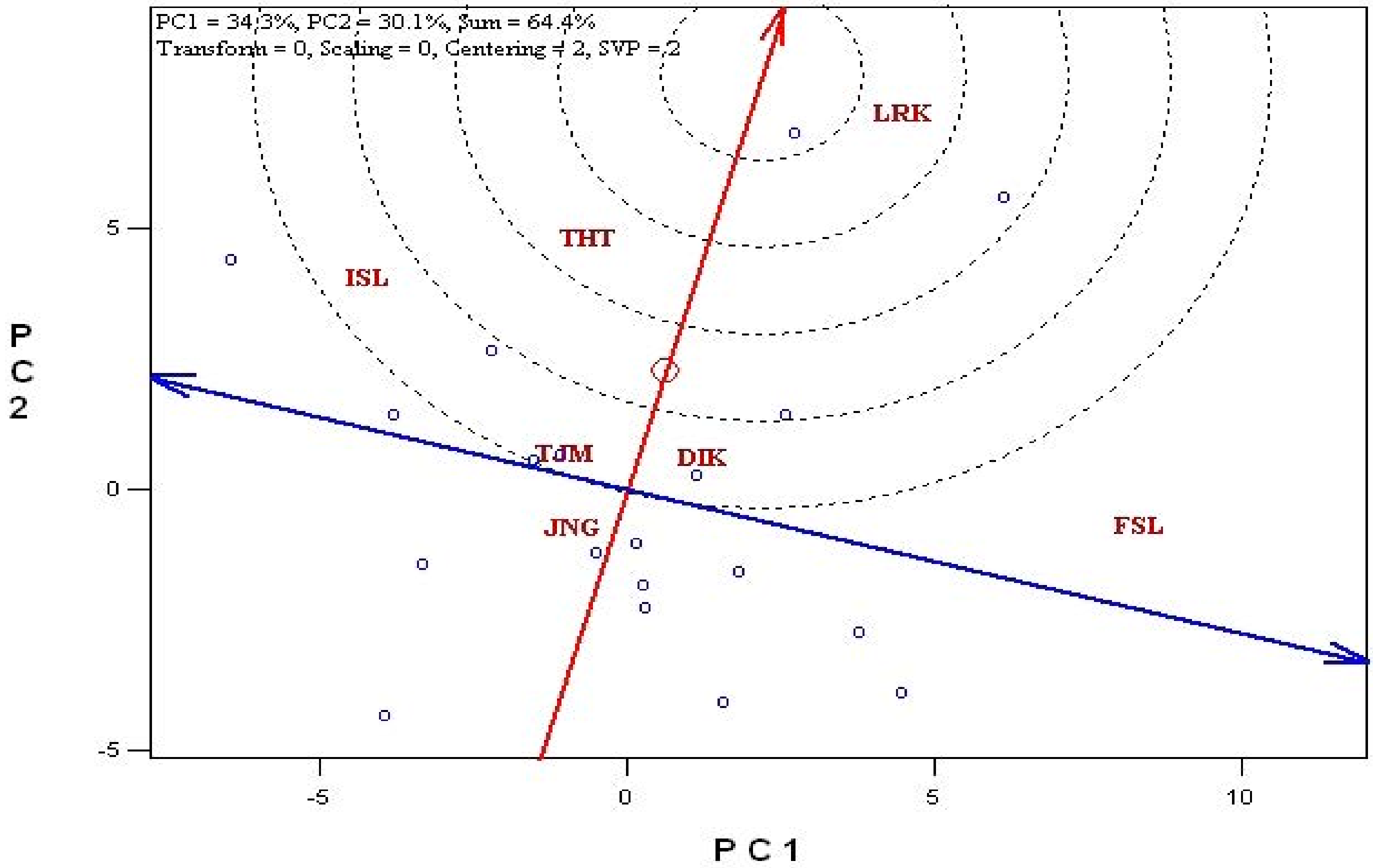

Figure 5: *Ranking of environments based on both discriminating ability and representativeness.*

yield and stability of performance as V-15 (HoTh-300), V-9 (LRK-2004), V-12 (CP NIA-82-223), V-14 (HoTh-127) and V-16 (HoTh-326) the top five, while V-3 (S2002-US-560), V-8 (LRK-2003), V-5 (S2002-US-640), V-11 (GT-11) and V-4 (S2002-US-637) are the bottom five varieties.

The GGE-biplot also shows the relationship between yield and stability with respect to the vectorial standpoint of the environment and they are connected by vectors with the origin of the biplot (Mattos et al., 2013). The lesser the difference between average yield of genotypes in an environment the less would be G × E interaction (Yan and Kang 2003; Fan et al., 2007). In present study Faisalabad (FSD) and Larkana (LRK) environments were the most unstable indicating greater G × E interaction (Figure 4). Similarly, the difference between the average yields of genotypes was the lowest in Dera Ismail Khan (DIK) and Tandojam (TJM) contributing lesser towards G × E interaction (Figure 4; Table 5). Figure 4 also shows relationship among the locations. The vectors of all seven locations represent the discriminating ability and the linear map at the right side of the graph (in degrees) helps in explaining the relationship among them. Islamabad and Tandojam had smaller angle between their vectors, similarly the angles between DIK and LRK is also smaller as compared to rest of the locations. According to Yan and Kang (2003) and Fan et al. (2007), the cosine of the angle between two vectors of locations represents correlation between them.

Discriminating ability and representativeness of the test locations can be measured as the absolute distance of location from the biplot origin and the length of the projection from the marker of location on to the ATC Y-axis (Yan, 2001). Thus, Larkana was identified as the most discriminating location as it had a larger projection on to ATC X-axis, followed by Thatta (Figure 5) while, D.I. Khan and Tandojam were identified as representative locations as they had smaller projections on to ATC Y-axis. Yan (1999) and Yan et al. (2000) reported that genotype by environment interaction with respect to discriminating ability and representativeness of test environments is a measure of desirability. Therefore, the desirable location must have highly discriminating ability as well as representative of all locations. The center of the concentric circles represents an "ideal" location that is most discriminating for varieties and is representative of all other locations (Yan, 2001; Yan and Kang, 2003).

Table 5: *Average cane yield (t ha^{-1}) of 19 sugarcane varieties at seven locations.*

Varieties	Environment/Location (E)							
	ISL	TJM	DIK	FSD	THT	LRK	JNG	Mean
V-1	64	90	76	83	73	126	85	85
V-2	106	83	66	63	76	129	96	88
V-3	103	91	77	55	60	76	104	81
V-4	79	94	95	133	85	99	95	97
V-5	64	88	61	93	63	105	104	83
V-6	101	93	62	85	74	112	101	90
V-7	63	94	83	58	56	133	100	84
V-8	69	96	61	133	62	107	92	89
V-9	107	93	81	140	102	180	76	111
V-10	68	79	75	83	102	98	96	86
V-11	106	91	49	58	85	96	84	81
V-12	89	81	98	97	85	144	91	98
V-13	100	85	94	97	99	96	85	94
V-14	92	91	71	45	108	139	91	91
V-15	92	82	74	83	116	192	89	104
V-16	118	95	50	125	106	105	95	99
V-17	131	91	84	95	88	110	103	100
V-18	133	93	79	63	103	104	85	94
V-19	149	132	74	45	123	118	114	108
Location mean	97	92	74	86	88	119	94	

Conclusions and Recommendations

The stability and adaptability studies of genotypes with GGE-Biplot indicated that HoTh-300 and LRK-2004 are the most productive genotypes in terms of tonnes of sugarcane per hectare and also indicated Larkana environment as the ideal location, most discriminating for varieties with the greatest G × E interaction and representative of all other locations.

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Author's Contribution

Muhammad Zubar: Conceived the idea, supervised and maanged the financial support to this study. Techncal input at ever step.
Sagheer Ahmad: Wrote abstract, Conclusion,Technical input at every step.
Overall management of the article.
Awais Rasool: Methodology, planted and managed field experiments.
Techincal input at every step. Data collection, References.
Muhammad Asad Farooq: Overall management of field trials. Technical input at every step, Data collection.
Ibni Amin Khalil: Data entry and statistical analysis, result and introduction, references.

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