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Nonparametric measures of phenotypic stability for commercial cane sugar yield in sugarcane

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Abstract

Nine sugarcane genotypes evaluated for commercial cane sugar yield under six environments. The objective of this investigation was to identify sugarcane genotypes with good phenotypic stability for sugar yield over the environments using nonparametric measures. Further, the relationship among nonparametric as well as some classical parametric measures of stability were also studied. Based on estimates $S_i^{(1)}$ and $S_i^{(2)}$ from uncorrected data, Co 1148 had shown maximum stability with low sugar yield, however, CoLk 9710 was most stable with high sugar yield based on $S_i^{(3)}$ measure. On the other hand, the values of $S_i^{(1)}$ and $S_i^{(2)}$ obtained from transformed data indicating that CoS 97264 had maximum stability. However, the estimate of $S_i^{(3)}$ from transformed data, reflected the maximum stability in CoLk 9606 for CCS yield. Based on the rank correlation among different measures of stability, $S_i^{(1)}$ and $S_i^{(2)}$ were nearly perfectly associated with high significant positive value indicating that two measures were similar in classifying the genotypes according to their stability over the environmental conditions. The statistic $S_i^{(3)}$ may be utilized for simultaneous selection for yield and stability.

Key words: Nonparametric measures, phenotypic stability, G x E interaction, sugarcane

Introduction

Sugarcane is a commercial crop, best adapted to tropical as well as sub tropical conditions and is widely grown in varying environment conditions. Sugarcane is the most important industrial crop in Brazil, India, Australia, China, Mauritius and Cuba. The farmers currently use varieties, which are more responsive to high input management. The yield performance of these varieties is very low when grown under the conditions of limited availability of inputs such as irrigation, fertilizers etc. Increase in the genetic potential of sugar yield is an important objective of sugarcane breeding programme in India and elsewhere. The improved sugarcane genotypes are being evaluated in different environmental conditions to test their performance and select the best genotype for high sugar yield and its stability across the environment.

Several methods such as regression analysis [1], multivariate clustering analysis [2, 3], multiplicative formulations such as additive main effects and multiplicative interaction [4] and nonparametric methods [5-7] may be used for the interpretation of G x E interaction. The present investigation was carried-out with the objective to test the phenotypic stability of sugarcane genotypes for sugar yield across the environments by using the nonparametric measures and also to study relationships among nonparametric stability as well as some classical parametric methods.

Materials and methods

This research data set involves nine sugarcane genotypes *viz.*, Co 1148, CoLk 9710, CoLk 9701, CoLk 94184, CoS 767, CoS 97264, CoLk 9617, CoLk 9606 and CoLk 8102 were tested in six environments (year-growing condition combinations) for commercial cane sugar (CCS) yield during 2002-2004. These environments were coded as E_1 (first plant crop under normal condition), E_2 (first plant crop under moisture deficit condition), E_3 (second plant crop under normal condition), E_4 (second plant crop under moisture deficit condition), E_5 (ratoon crop under normal condition) and E_6 (ratoon crop under moisture deficit condition). The experiments were planted according to standard practice. Plots were 18 m^2 with four rows each 6 m long and 75 cm between rows. The mean CCS yield was estimated for each genotype in each environment. In this investigation, three nonparametric measures of stability [5] were applied to test the significance of G x E interaction for CCS yield. For a two way data with 'k' genotypes and 'n' environments, r_{ij} was denoted as the rank of the i^{th} genotype in the j^{th} environment and $\bar{r}_i$ as the mean rank across all the environments for the i^{th} genotypes. The nonparametric statistics based on yield ranks of genotypes in each environment are expressed as follows:

$$S_i^{(1)} = 2 \sum_{j}^{n-1} \sum_{j'=j+1}^{n} [r_{ij} - r_{ij'}]/[n(n-1)]$$

$$S_i^{(2)} = 2 \sum_{j=1}^{n} [r_{ij} - \bar{r}_i]^2/[n-1]$$

$$S_i^{(3)} = 2 \sum_{j=1}^{n} [r_{ij} - \bar{r}_i] / \bar{r}_i$$

These nonparametric stability parameters *viz.*, $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ were estimated from uncorrected as well as corrected data. The values of corrected data were obtained by using $y^c_{ij} = (y_{ij} - (y_i - y)$ where, y^c_{ij} = corrected value of i^{th} genotype in j^{th} environment, y_{ij} = uncorrected value of i^{th} genotype in j^{th} environment, y_i = mean of the i^{th} genotype over all the environments and y = population mean. In addition, four classical measures of stability, namely, mean (X), regression coefficient (b_i), deviation from regression (S^2d_i) and environmental variance ($Á^2_w$) were also estimated. To determine relationships among different classical and nonparametric measures of phenotypic stability, Spearman's rank correlations were used among the rank orders based on these stability measures.

Results and discussion

The estimates of $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ and X^2 values obtained for uncorrected as well as corrected data are given in Table 1. In uncorrected data, $X^{2(1)}$ and $X^{2(2)}$ were highly significant at nine degree of freedom for CCS yield. However, their significance is not a clear indication of significant stability differences between genotypes since the variation for CCS yield may also be a cause of these significant values. The values of X^2 for individual genotypes at one degree of freedom were significant for Co 1148, CoLk 9710, CoLk 9701, CoS 97264 and CoLk 9606. The genotype Co 1148 had least values of $S_i^{(1)}$ and $S_i^{(2)}$ indicating maximum stability followed by CoLk 9710 and CoLk 9606. Based on the estimates of $S_i^{(3)}$ from the original data, the genotype CoLk 9710 was most stable followed by CoLk 8102 and CoLk 9606. If the main criterion is the simultaneous consideration of both yield and stability, it is better to apply these nonparametric measures using the original uncorrected data since transformation of data reduces significance of stability measures drastically [5]. It is explained that if estimation of stability independent from yield level

Table 1. Estimates of three nonparametric stability measures and X^2 values for commercial cane sugar

Genotype	$S_i^{(1)}$	$X^{2(1)}$	$S_i^{(2)}$	$X^{2(2)}$	$S_i^{(3)}$
Uncorrected data					
Co 1148	0.53	11.11**	0.27	4.73	2.00
CoLk 9710	0.60	10.51**	0.30	4.68	0.35
CoLk 9701	1.20	5.84*	1.08	3.62	1.40
CoLk 94184	2.07	1.51	2.97	1.58	1.26
CoS 767	2.67	0.16	3.87	0.91	3.00
CoS 97264	1.21	5.84*	1.07	3.62	1.75
CoLk 9617	1.73	2.84	2.00	2.52	0.86
CoLk 9606	1.07	6.76**	0.80	3.97	0.80
CoLk 8102	1.33	4.99	1.87	2.66	0.79
Sum ($X^2_{9\,df}$)		49.57**		28.29**	
Corrected data					
Co 1148	3.53	0.62	9.37	0.84	2.63
CoLk 9710	2.80	0.05	5.77	0.09	2.34
CoLk 9701	2.81	0.05	5.47	0.17	2.43
CoLk 94184	4.13	2.60	11.47	2.65	3.44
CoS 767	4.60	5.07*	15.37	8.72*	4.06
CoS 97264	2.20	1.09	3.87	0.91	1.86
CoLk 9617	3.53	0.62	9.07	0.66	3.43
CoLk 9606	2.27	0.91	4.40	0.59	1.60
CoLk 8102	2.87	0.02	5.50	0.16	1.63
Sum ($X^2_{9\,df}$)		11.02		14.80	

* and **significant at 5 and 1 percent of probability level, respectively

effects, one should compute rank stability measures after correcting the data. The values of nonparametric measures and their corresponding X^2 values obtained from corrected data, however, presented an altogether different picture. Global value of $X^{2(1)}$ and $X^{2(2)}$ were both non significant indicating absence of varietal difference for phenotypic stability for commercial cane sugar in transform data. The estimates of $S_i^{(1)}$ and $S_i^{(2)}$ from corrected data reflected that CoS 97264 was most stable for sugar yield followed by CoLk 9606 and CoLk 9701. Based on the estimates of $S_i^{(3)}$ CoLk 9606 had shown maximum stability followed by CoLk 8102 and CoS 97264. The value of $X^{2(1)}$ and $X^{2(2)}$ for individual genotypes were also non significant except CoS 767 for which both X^2s were significant. Significance for only one variety is not enough to justify the presence of varietal differences for stability and may be attributed to a chance factor. Thus, it may further be concluded that the transformation of data resulted in a considerable increase in the estimates of $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ and a drastic reduction in the significance.

The statistics, $S_i^{(1)}$ and $S_i^{(2)}$, were based on the rank of genotypes across the environments and they give equal weight to each environment. The $S_i^{(1)}$ estimates are based on all possible pair wise rank difference across environment for each genotype, whereas $S_i^{(2)}$ is based on variance of ranks for each genotypes across environments. According to both $S_i^{(1)}$ and $S_i^{(2)}$, Co 1148 had the smallest changes in ranks and is thus regarded as the most stable genotype followed by CoLk 9710 and CoLk 9606. $S_i^{(3)}$ combines yield and stability based on yield ranks of genotypes in each environment [5]. Rank based on the $S_i^{(3)}$ estimates, CoLk 9710 was the most stable genotype followed by CoLk 8102 and CoLk 9606. The mean CCS yield was lowest for Co 1148 and highest for CoLk 9710.

The ranks based on the seven measures of stability are given in Table 2. Except the means where rank 1 was given to highest mean and rank 9 to lowest mean, in all the cases rank 1 was given to lowest value of the measures and rank 9 to the highest value. To determine relationships among different parametric and nonparametric measures of stability for CCS yield, rank correlations were computed (Table 3). There were positive but non-significant correlation between the non-parametric measures obtained from uncorrected data and those from corrected data. The three non parametric measures were highly positively correlated among themselves in corrected data. These findings suggested that any one of three nonparametric statistics derived from the corrected data can be used for the identification of stable genotypes. The correlation between mean CCS yield and $S_i^{(3)}$ was positive and highly significant but with $S_i^{(1)}$ and $S_i^{(2)}$ it was low and negative in corrected data, it indicated that only $S_i^{(3)}$ statistic would be useful for simultaneous selection for high yield and stable performance across the different environments. It is also evidenced by this study that CoLk 9710 occupied first rank for both mean CCS yield and $S_i^{(3)}$ statistic derived from uncorrected data.

Table 2. Rank order of sugarcane genotypes based on different measures of stability

Genotype	Measures of stability									
		Uncorrected data						Corrected data		
	Mean	b_i	S^2d_i	σ^2_w	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$
Co 1148	9	5	8	7	1	1	8	7	7	6
CoLk 9710	1	3	5	4	2	2	1	3	5	4
CoLk 9701	6	4	4	3	4	5	6	4	3	5
CoLk 94184	3	9	7	9	8	8	5	8	8	8
CoS 767	8	1	9	2	9	9	9	9	9	9
CoS 97264	7	6	2	5	5	4	7	1	1	3
CoLk 9617	2	2	3	1	7	7	4	6	6	7
CoLk 9606	5	8	1	8	3	3	3	2	2	1
CoLk 8102	4	7	6	6	6	6	2	5	4	2

Table 3. Rank correlation among the non-parametric and parametric measures of stability for commercial cane sugar

		Measures of stability							
		Uncorrected data				Corrected data			
Mean	b_i	S^2d_i	σ^2_w	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$
Uncorrected data									
Mean	-0.067	0.300	0.067	-0.100	-0.117	0.850**	0.167	0.033	0.117
b_i		-0.233	0.917**	-0.117	-0.150	-0.267	-0.250	-0.333	-0.467
S^2d_i			0.017	0.267	0.222	0.417	0.850**	0.850**	0.667*
σ^2_w				-0.267	-0.300	-0.150	-0.083	-0.100	-0.333
$S_i^{(1)}$					0.983**	0.233	0.533	0.433	0.550
$S_i^{(2)}$						0.217	0.583	0.467	0.583
$S_i^{(3)}$							0.433	0.333	0.567
Corrected data									
$S_i^{(1)}$								0.950**	0.850**
$S_i^{(2)}$									0.867**
$S_i^{(3)}$									

* and **, significant at 5 and 1 percent of probability level, respectively.

The correlations between the regression coefficient and each of the nonparametric stability measures were low and negative. The correlations between environmental variance (σ^2_w) and each of the nonparametric measures were also very low and negative. The correlation of regression coefficient as well as environmental variance with $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ in most situation were not statistically significant. The correlation between deviation from regression and each of the statistics were positive and low to medium value. Based on rank correlations between parametric and nonparametric measures of stability, it is concluded that they can not be replaced with each other. The non parametric statistics seems to be useful alternative to parametric measures, although they do not provide any information regarding the genotypic adaptability. The $S_i^{(1)}$ and $S_i^{(2)}$ were nearly perfectly associated with highly significant positive value indicating that the two measures were similar in classifying the genotypes according to their stability under different environment conditions. Consequently, only one of these parameters would be sufficient to select the stable genotype for CCS yield. Significant positive correlation was also found among $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ measures [8]. Similarly, high rank correlations were reported between $S_i^{(1)}$ and $S_i^{(2)}$ by different workers.

As per the earlier findings [10], $S_i^{(1)}$ and $S_i^{(2)}$ were associated with the static concept of stability which explained by a genotype with a minimal variance for yield across different environments. Based on the statistics, $S_i^{(1)}$ and $S_i^{(2)}$ as well as associated static concept, the Co 1148 was identified as most stable genotype with low CCS yield. The static concept of stability is not acceptable to most of the breeders, who prefer genotypes good stability with high mean CCS yield and potential to respond to better environmental conditions as explained by dynamic concept of stability. Based on the statistic $S_i^{(3)}$, associated with the dynamic concept of stability, the CoLk 9710 was identified as most stable genotype with high CCS yield across different environmental conditions. The genotype CoLk 9710 had also shown maximum stability for sucrose % as well as cane height [11]. They considered as most important components in determining the CCS yield.

On the basis of these findings, it can be concluded that sugarcane genotype CoLk 9710 was found most stable with high CCS yield under the given set of environmental conditions having dynamic stability. Thus, it can be put to the cultivation in wide areas and may remain in cultivation for longer period. Based on the rank association, it may be suggested that the out of two statistics $S_i^{(1)}$ and $S_i^{(2)}$, any one of them may serve the purpose. Moreover, the statistic $S_i^{(3)}$ may be utilized for simultaneous selection for yield and stability. It is also concluded that genotype Co 1148 had shown stability of static concept resulted due to the homoeostasis or buffering capacity. This ability of stable genotype depends on the broader genetic base. The genotype Co 1148 having broad genetic base thus, may be utilized as parents in breeding programme.

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