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Stability analysis using various parametric and non-parametric methods in single and three-way cross hybrids of maize (Zea mays L.)

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Abstract

Farmers are always on the lookout for stable and high yielding maize hybrids in the competitive seed market. G x E interaction is the main challenge faced by the maize breeders in the development of single and three way cross hybrids in private and public breeding programs. Looking to the several methodologies applied for stability, it was thought to apply five parametric stability procedures viz., Eberhart and Russel's regression technique, Shukla's stability variance ($Sh\text{-}\sigma^2$), genotype grouping technique based on Francis and Kanenberg's coefficient of variation (CVi), Lin and Binn's Cultivar superiority index (P_i) and Harnandez's Desirability index (D_i) and three non-parametric procedures viz., Huhn's rank stability measures S_i^1 and S_i^2 and Kang's Rank Sum (RS) for assessment of 20 single and seven three-way cross hybrids evaluated at six locations, which represent important maize growing ecologies in India, during winter season of 2015. Spearman rank correlation coefficients were worked out to assess the association between stability procedures. All the three components in Eberhart and Russel model i.e., environment (Lin.), G x E (Lin.) and pooled deviations were found significant. Hybrid SC18 was found high yielding, stable and adaptable to all the environments. Hybrids SC9, SC10 and SC14 were found stable and well adaptable to favourable environments whereas hybrids SC16 and TWC24 were found not only high yielding and stable but also suitable for marginal environments and they would be preferred by farmers as most of them cultivate maize under marginal environments. Almost all parametric and non-parametric methods unanimously selected SC16, SC10 and SC18, in that order, as potential hybrids among single crosses and TWC24 among three-way crosses. Significant positive rank correlation coefficients were obtained between all possible pairs of S^2d_i, $Sh\text{-}\sigma^2$, CV_i, S_i^1 and S_i^2 and Kang's RS implying that anyone of these parameters could be used to describe genotypic stability. Significant positive correlation between parametric and non-parametric stability measures indicated that rank-based non-parametric methods can be used as viable alternative to the existing parameters. Single and three-way cross hybrids were equally stable and desirable as indicated by various stability measurers. P_i, D_i and Kang's RS emphasized SC hybrids as most high yielding and stable whereas $Sh\text{-}\sigma^2$, Huhn's S_i^1 and S_i^2 indicated that TWC hybrids are stable and assured yielders under marginal environments.

Keywords: maize, GEI, stability, ebarhart & russel, parametric, non-parametric, single cross, three-way cross, grain yield

1. Introduction

Maize (Zea mays L.) is the world's most widely grown cereal. It is the key crop for food and food security and income generation for millions of farmers (B.M. Prasanna, 2014). Globally, 167 countries produced 1021 million tons (mt) of maize from the area of 183 million hectares (m.ha) in 2014 (FAOSTAT). India is the second and sixth largest producer of maize in Asia and World respectively, with an area of 8.6 m. ha and production of 23.6 mt. In India, demand of hybrid maize seed is majorly being met by private seed industry which is supplying around one lakh tons per year accounting over Rs. 1500 crore (Economic times, 9/4/2014). Farmers take up maize cultivation in diverse environmental conditions ranging from very high-input to extremely poor managements. And they are always on the lookout for high yielding stable varieties suitable for their growing conditions.Because each plant or cultivar has its inherent and characteristic ability to buffer and respond to fluctuating growing conditions, the differential responses of cultivars to a range of environments leads to genotype-environment (GE) interactions (Abera *et al.*, 2006) [1]. There is a need to investigate the genotype-environment interaction (GEI) which can be useful in micro-organization (targeting cultivars to specific environments). With GE interaction, the effect of cultivars and environments are statistically non-additive, which means that differences in cultivar yields depend on the environment. (Henry et.al, 2014) [11].

The adaptability of a genotype in diverse environments is usually tested by the degree of its interaction with the conditions under which it is planted. A genotype is considered to be more adaptive or stable if it has a high mean yield but a low degree of fluctuation in yielding ability when grown in diverse environments. The knowledge of genotype x environment interaction (GEI) and stability of genotypes across environments is essential for breeding program. Significant GEI makes selection using cultivar means across environments less efficient (Hopkins at al. 1995) [13]. Because, some genotypes are adapted to a broad range of environmental conditions, while others are more limited in their potential distribution. Some genotypes that have similar performance regardless of the productivity level of the environment, and there are others whose performance is directly related to the productivity potential of the environment, clearly indicating the importance of stability analysis. GEI creates problems in identifying superior genotypes (Kaya *et al*. 2014) [17]. The performance test of genotypes over a series of environments gives information on GEIs, but does not measure the stability and adaptability of varieties. It is prerequisite to evaluate a cultivar behavior across environments to find out cultivars with general or specific adaptation before release. Several biometrical methods including parametric and nonparametric approaches have been developed to assess stability (Crossa, 1990) [5]. The parametric strategy includes the methods which are based on variance components and joint regression, while non-parametric approaches are based on the ranks of genotypes in each environment.

Although several parametric models for the statistical measurement of the stability have been proposed, each of which reflects different aspects of stability and no single method can adequately explain genotype performance across environments. Regression technique was first discussed by Yates and Cochran (1938) [28] and later by Finlay and Wilkinson (1963) [9] to measure stability and then was improved by Eberhart and Russell (1966) [8]. Some other parametric stability statistics are: Shukla's (1972) stability variance (Sh-σ^2), genotype grouping technique based on Francis and Kanenberg's (1978) [10] coefficient of variation (CVi), Lin and Binn's (1988) [19] Cultivar superiority index (P_i) and Harnandez's (1993) Desirability index (D_i)

Nonparametric methods also give viable alternate options which are based on the ranks of genotypes in each environment and use the idea of homeostasis (environmental resistance) as a measure of the stability. Nassar and Huhn (1987) [21] proposed two rank stability measures i.e., S_i^1 (mean absolute rank differences) and S_i^2 (variance among the ranks over environments). Kang (1988) [18] proposed Kang's Rank Sumparameter by combining cultivar yield rank and Shukla's stability variance rank into one statistic.

Stability indices allow researchers to identify widely adapted genotypes for using in breeding programs and help improving recommendations to the growers (Mohebodini *et al*. 2006) [20]. The stability parameters were studied in maize to measure phenotypic or agronomic stability but it is still very important information that should be available for commercial hybrids for marketing purpose. Therefore, present study evaluates some initial stage single (SC) and three-way cross (TWC) hybrids of maize selected from LxT studies for their yield stability under different maize growing states of India to compare and evaluate the usefulness of various parametric and non-parametric methods for estimating agronomic stability.

2. Materials and Methods

2.1 Planting materials and testing locations

Twenty single (SC) and seven three-way cross (TWC) hybrids exhibiting significant positive SCA effects as well as standard heterosis for grain yield were identified from the combining ability experiment done with fifteen lines, four inbred and two single cross testers during kharif-2015. To these 27 crosses, three commercial checks i.e., NK-6240 (G28), 30V92 (G29) and 900M Gold (G30) were added to make up 30 genotypes. Single crosses were coded from SC1 to SC20 whereas three-way crosses were coded from TWC21 to TWC27. These 30 genotypes were used for stability experiment in the six locations viz., Medak (E1), Aurangabad (E2), Davanagere (E3), Dindigul (E4), Guntur (E5) and Bhagalpur (E6) during Rabi-2015 (November to April). Description of the six test locations and list of hybrids are presented in Tables 1 and 5 respectively.

Table 1: Description of test locations

Location code	Location	State	Latitude	Longitude	Altitude (masl)	*Average annual rainfall (mm)	Soil type
E1	Medak	Telangana	17º37`N	78º39`E	586	821	Red soil
E2	Aurangabad	Maharashtra	19º58`N	75º23`E	769	710	Black soil
E3	Davanagere	Karnataka	14º28`N	75º51`E	597	644	Black soil
E4	Dindigul	Tamil nadu	10º27`N	78º01`E	284	812	Black soil
E5	Guntur	Andhra Pradesh	16º19`N	80º20`E	39	906	Red soil
E6	Bhagalpur	Bihar	25º19`N	87º02`E	43	1111	Loamy soil

* Rainfall during Rabi season in which trials were conducted is almost nil.

Table 5: Mean yield (t/ha) and different stability parameters of 30 maize genotypes tested at six locations, Rabi-2015

S. No	Hybrid	Code	Mean yield (t/ha)		b_i		S^2d_i		Sh-σ^2		CV_i		P_i		D_i		Huhn S_i^1		Huhn S_i^2		Kang's RS
			Value	R	Value	R	Value	R	Value	R	Value	R	Value	R	Value	R	Value	R	Value	R	Value	R
1	NMH-5	SC1	11.64	13	1.829	30	-0.292	10	2.103**	25	25.89	29	4.38	12	12.27	11	7.733	28	111.5	28	38	22
2	NMH-6	SC2	11.62	14	1.147	12	0.908*	22	1.235**	18	18.53	23	4.95	16	12.02	14	4.333	6	42.3	13	32	18
3	NMH-8	SC3	12.28	5	1.074	7	1.417**	25	1.625**	22	17.49	21	3.45	8	12.65	6	6.667	25	63.5	25	27	9
4	NMH-14	SC4	11.19	20	1.199	14	3.01**	30	3.088**	29	23.02	26	5.97	20	11.61	19	8.467	29	141.1	30	49	28
5	NMH-16	SC5	11.57	15	0.624	23	0.388	14	1.129**	16	11.47	4	5.02	17	11.79	15	4.800	9	54.4	19	31	17
6	NMH-18	SC6	12.49	4	0.952	3	1.543**	26	1.724**	23	16.13	14	2.75	4	12.82	4	5.800	19	46.7	17	27	10
7	NMH-22	SC7	11.43	17	1.015	2	0.681	17	0.979**	15	16.82	19	4.63	13	11.78	16	5.267	13	54.4	20	32	19
8	NMH-23	SC8	11.16	21	1.002	1	0.37	13	0.71	9	16.47	18	5.73	19	11.51	20	3.533	2	32.6	8	30	16
9	NMH-24	SC9	12.12	7	1.202	15	0.22	8	0.70	8	17.36	20	2.91	5	12.53	7	5.400	15	42.4	14	15	3
10	NMH-26	SC10	12.75	3	1.211	16	0.08	4	0.59	6	16.40	17	2.02	2	13.17	2	5.133	11	35.9	9	9	2
11	NMH-27	SC11	11.74	11	0.888	10	0.511	15	0.869*	13	14.55	10	4.01	10	12.05	13	4.733	8	43.1	15	24	8
12	NMH-28	SC12	12.79	2	0.661	22	2.516**	29	2.879**	27	14.81	11	2.36	3	13.02	3	6.733	26	59.1	21	29	12
13	NMH-38	SC13	12.18	6	0.667	21	0.179	7	0.864*	12	10.83	2	3.13	7	12.41	9	5.867	21	41.5	12	18	4

14	NMH-39	SC14	11.70	12	1.285	20	0.706	19	1.232**	17	19.81	24	3.96	9	12.14	12	5.533	16	59.5	22	29	13
15	NMH-40	SC15	10.93	23	1.448	25	0.685	18	1.554**	20	23.39	27	6.65	22	11.43	22	6.600	24	63.0	24	43	25
16	NMH-43	SC16	12.91	1	0.784	17	-0.03	2	0.50	4	11.02	3	1.73	1	13.18	1	4.400	7	13.2	1	5	1
17	NMH-48	SC17	12.06	9	1.734	29	1.842**	28	3.511**	30	26.07	30	4.02	11	12.66	5	7.133	27	83.6	27	39	23
18	NMH-53	SC18	12.08	8	1.051	4	0.634	16	0.946**	14	16.26	15	3.06	6	12.44	8	5.733	18	40.7	11	22	7
19	NMH-54	SC19	11.31	19	0.914	9	-0.13	6	0.31	2	14.07	9	5.18	18	11.63	18	3.000	1	19.1	3	21	5
20	NMH-56	SC20	10.28	28	1.125	11	1.342**	24	1.59**	21	21.43	25	9.88	28	10.67	27	5.933	23	53.4	18	49	29
21	NMH-64	TWC21	10.68	24	0.916	8	1.229**	23	1.468**	19	17.83	22	8.15	26	11.00	24	5.800	20	61.5	23	43	26
22	NMH-68	TWC22	10.36	27	0.77	18	-0.315	11	0.28	1	12.72	6	8.52	27	10.63	28	4.267	5	20.6	4	28	11
23	NMH-72	TWC23	10.56	26	0.943	5	0.029	1	0.43	3	15.85	13	7.59	25	10.89	25	3.800	3	22.2	5	29	14
24	NMH-74	TWC24	11.51	16	0.742	19	-0.085	5	0.51	5	11.69	5	4.80	15	11.76	17	4.000	4	26.6	7	21	6
25	NMH-80	TWC25	10.66	25	0.586	24	-0.048	3	0.842*	11	10.65	1	7.56	24	10.86	26	5.267	14	39.1	10	36	20
26	NMH-84	TWC26	9.60	29	0.506	26	0.894*	21	1.856**	24	14.02	8	12.91	30	9.77	30	5.533	17	25.1	6	53	30
27	NMH-88	TWC27	9.54	30	0.823	13	0.276	9	0.72	10	16.37	16	12.76	29	9.82	29	5.200	12	13.6	2	40	24
28	NK-6240	Check1	11.76	10	1.606	27	0.819*	20	2.145**	26	23.95	28	4.70	14	12.31	10	5.867	22	77.9	26	36	21
29	30V92	Check2	11.33	18	0.362	28	1.717**	27	3.028**	28	12.90	7	6.70	23	11.45	21	8.467	30	128.6	29	46	27
30	900M Gold	Check3	11.00	22	0.932	6	0.319	12	0.68	7	15.68	12	6.53	21	11.33	23	5.000	10	45.1	16	29	15

Note: b_i: Regression coefficient, S^2d_i: Deviation from regression, Sh-σ^2: Shukla's stability variance,CV_i: Francis and Kannenberg's coefficient of variation,P_i: Lin and Binn's Cultivar performance measure, D_i: Desirability index, S_i^1& S_i^2: Huhn's stability measures, Kang's RS: Kang's rank-sum

2.2 Experiment layout and design

The experimental layout was randomized complete block design with three replications. At each site, planting was done in plots of 9.6 m^2 with 4 rows measuring 4m. The seed was sown at 60 x 25 cm spacing. All recommended cultural practices were followed for all locations to raise a good crop. Grain yield of each genotype was recorded on a plot basis and later converted into t/ha at 15% grain moisture.

2.3 Data analysis

The data analysis was conducted using Indostat services of Hyderabad. The grain yield data on multi-location trials (MLT) were analyzed on individual and pooled basis as per RBD. The same data were also used to estimate different stability parameters as listed below.

Spearman rank correlations were worked out to study the association between different stability parameters.

3. Results and Discussions

3.1 Mean yields and Combined ANOVA

Grain yield data of 30 maize hybrids were subjected to analysis of variance for individual location as well as pooled over locations. The Analysis of Variance (ANOVA) of individual locations presented in Table 2 indicated that the variance for genotypes was found significant in all the locations. This suggests the presence of variability among the genotypes under study (Anandan *et al* 2009) [2]. The coefficient of variation (CV%) ranged from 6.82 (E3, Davanagere) to 14.5 (E2, Aurangabad). Looking at environmental index, the locations E1 and E6 were high yielding, E3 and E5 were low yielding environments whereas remaining E2 and E4 environments gave medium yield. The mean grain yield of test hybrids across locations varied from 9.54 t/ha for TWC27 to 12.91 t/ha for SC16, with overall environmental mean of 11.44 t/ha and the best check NK-6240 yielded 11.76 t/ha. SC hybrids exhibited higher mean yield of 11.81 t/ha over TWC hybrids, whose average was10.42 t/ha.

Results of analysis of variance over locations presented in Table 3 gave the overall picture of the relative magnitude of the genotype (G), environment (E) and genotype-environment interaction (GEI) variance. The combined ANOVA revealed that genotype, environment and G x E interaction were highly significant and contributed 18.06, 55.14 and 26.80 per cent of trial variation (Kaya *et. al.,* 2006, Parmer D. J *et.al.,* 2016) [16, 22]. This result shows that grain yield was significantly affected by changes in environment followed by G x E interaction and genotypic effects (Tamene Temesgen et.al., 2015) [27]. The highly significant environment effect and its variance component could be attributed to the large differences in latitude, longitude, temperatures and soil type. The amount of variance contributed by G x E interaction was larger than that contributed by genotype. This result indicated that there was a marked G x E interaction effect present in maize, leading to the presence of substantial differences in genotypic responses across the test environments.

Table 2: Analysis of variance for individual location

Source	df	Mean squares					
		Medak (E1)	Aurangabad (E2)	Davangere (E3)	Dindigul (E4)	Guntur (E5)	Bhagalpur (E6)
Replication	2	0.052	0.114	1.565	0.417	2.273	1.021
Genotype	29	5.66**	4.03**	3.74**	5.56**	6.72**	7.84**
Error	60	2.470	2.560	0.540	1.040	1.320	1.350
C.V. (%)	-	12.56	14.50	6.82	8.98	11.34	8.18
Overall mean (t/ha)	-	12.72	11.20	10.11	11.38	9.41	13.82
Yield range (t/ha)	-	8.96-15.98	9.59-13.36	8.32-12.28	8.87-14.55	6.38-12.78	10.77-17.59
Environmental Index	-	1.282	-0.238	-1.332	-0.059	-2.035	2.382
CD 95%	-	2.612	2.654	1.127	1.670	1.743	1.847

Table 3: Analysis of variance for Pooled over locations

Source of variation	Df	SS	SS (%)	MS	F-value
Repl/Environments	12	18.90		1.58	1.01
Environments	5	1196.30	55.14	239.20	154.2**
Genotypes	29	391.70	18.06	13.50	8.70**
G x E	145	581.40	26.80	4.00	2.58*
Pooled error	348	539.40		1.55	
Total	539	2727.70			

3.2 Parametric stability methods

3.2.1 Eberhart and Russell Model Analysis

Results of analysis of variance as per Eberhart and Russell (1966) are presented in Table 4, which indicated that mean sum of squares due to genotypes were found to be significant which indicated that genotypic differences justified the selection of material. Mean sum of squares due to environment were found significant indicating the direct effect of environmental variation for grain yield. In stability analysis, environment and GEI component were further partitioned into environment (linear), G x E (linear) and pooled deviations from regression (non-linear component). The additive environmental variance was found to be of considerable magnitude as indicated by the significance of variance due to environment (linear) for grain yield. Significant *e* (linear) variance mean variation among environments is linear. A linear environmental variance signified unit changes in environmental index for each unit change in environmental conditions. Both MSS due to pooled deviation and G x E (linear) were found to be significant which indicated that only a part of the variations in performance of genotypes is predictable. Significant G x E (linear) implied differential yield performance of genotypes under diverse environments but with considerably varying reaction norms i.e. linear sensitivity of different genotypes was variable. Besides, significant pooled deviation suggested the performance of different hybrids fluctuated significantly from their respective linear path of response to environments. (Hugo-Ferney *et al*., 2006 and Shinde *et al*., 2004) [14, 24].

According to joint regression model developed by Eberhart and Russell, a stable variety is one with a high man yield, regression coefficient equals to one ($b_i = 1$) and deviation from regression equals to zero ($S^2d_i = 0$). The stability parameters for all the genotypes are given in Table 6. Rank of b_i values are given on the basis of bi-1. In the present study, the regression coefficient values (b_i) ranged from 0.362 (TWC29) to 1.829 (SC1). Thirteen out of 20 single crosses and five out of seven three-way crosses had non-significant S^2d_i which indicated their stability over environments.

Among SC hybrids, SC18 had higher yield (12.08 t/ha) than overall mean, unit regression coefficient (1.051) and non-significant S^2d_i (0.634^{ns}). Thus, it was stable and high yielding genotype which can be adapted to all the environments. Genotypes SC9, SC10 and SC14 had higher mean than overall mean, b_i greater than unity and non-significant S^2d_i. Therefore, these genotypes were stable and well adaptable to favorable environments. Genotype SC1 showed very high b_i (1.829) and non-significant S^2d_i with yield closer to overall yield. Therefore this particular hybrid is specifically adaptable to high input management with latest production technology. SC16 exhibited highest yield (12.91 t/ha) and non-significant S^2d_i along with b_i lower than one (0.784). Hence this genotype is the best yielder with highest level stability and it can be safely recommended to medium management conditions. Similarly, SC11 and SC13 are the next best yielders and they can also be recommended safely to medium management conditions as they showed non-significant S^2d_i with lesser b_i than one. Genotypes SC2, SC3, SC4, SC6, SC12, SC17, and SC20 were found unstable due to their significant S^2d_i values (Akcura *et al*., 2005) [16]. Among TWC hybrids TWC24 exhibited highest yield of 11.51 t/ha that was higher than overall yield and better than two checks, lower regression coefficient of 0.742 and non-significant S^2d_i. Hence it can be considered as high yielding, stable and recommended for cultivation as other SC hybrids.

Table 4: Analysis of variance for Stability model (Eberhart and Russel model, 1966)

Source of variation	D.F	SS	Source of variation	D.F	SS
Total	179	765.12	4.27		
Genotypes	29	130.58	4.502	3.66**	
Env.+(Genotypes*Env)	150	634.54	4.23	3.43**	100.0
Environments(Lin.)	1	398.69	398.69	323.95**	62.83
Genotypes*Env.(Lin.)	29	88.17	2.27	1.84*	13.89
Pooled deviation	120	147.68	1.231	2.427**	23.27
Pooled error	348	176.45	0.507		

Table 6: Mean yield (t/ha) and different stability parameters of single and three-way cross groups tested at six locations, Rabi-2015

S. No	Hybrid group	Mean yield (t/ha)	b_i	S^2d_i	Sh-σ^2	CV_i	P_i	D_i	Huhn S_i^1	Huhn S_i^2	Kang's RS
1	Single cross (SC)	11.81	1.091	0.829*	1.74	17.59	4.29	12.19	5.64	55	28
2	Three way cross (TWC)	10.42	0.755	0.284	1.39	14.16	8.9	10.68	4.975	35.8	36
3	Checks mean	11.36	0.966	0.951*	2.59	17.51	5.98	11.7	6.444	83.8	37

Note: b_i: Regression coefficient, S^2d_i: Deviation from regression, Sh-σ^2: Shukla's stability variance,CV_i: Francis and Kannenberg's coefficient of variation,P_i: Lin and Binn's Cultivar performance measure, D_i: Desirability index, S_i^1& S_i^2: Huhn's stability measures, Kang's RS: Kang's rank-sum

3.2.2 Shukla's stability variance (Sh-σ^2)

Shukla (1972) [25] explained the stability variance of genotype as its variance across environments after the main effects of environmental means have been removed. Since the genotype main effect is constant, the stability variance is thus based on the residual ($GE_{ij}+ e_{ij}$) matrix in a two-way classification. The stability statistic is termed as "stability variance" (σ^2_i). He partitioned GEI sum of square into variance components (Sh-σ^2) corresponding to each of the genotypes. Based on these variance components, a genotype is stable if its stability variance (Sh-σ^2) is equal to environmental variance (Sh-σ^2), which mean that Sh-σ^2 = 0. A relatively larger value of Sh-σ^2 indicates higher instability of genotype 'i', whereas stable genotypes are those having minimum stability variance (Sh-σ^2). This approach is considered of practical importance because it identifies environmental factors that contribute to the heterogeneity in the GEI.

Results for stability variance and overall means are summarized in Table 5 for grain yield of maize with their ranking order. Results indicated that the most stable genotypes in the decreasing order were TWC22, SC19, TWC23, SC16, TWC24, SC10, TWC30, SC9, SC8 and TWC27 as they showed non-significant values of Sh-σ^2. But, out of them, only three SC hybrids SC16, SC10 and SC9 exhibited very high yield potentiality with respective mean yield ranks of 1st, 3rd and 7th. These three hybrids can be aptly released for commercial cultivation as they exhibited both high yield potentiality and lower values of stability variance. Among TWC hybrids, TWC24 had shown very good stability due to its non-significant stability variance coupled with higher grain yield which was at par with overall yield. Another, three-way cross hybrid TWC22 exhibited highest level of stability by showing lowest value of Sh-σ^2 (0.276) but with moderate yield. The genotypes TWC1, SC12, SC4, SC17and two checks 30V92 and NK-6240 had poor stability according to this procedure.

3.2.3 Francis and Kannenberg's coefficient of variation (CV_i)

The genotype grouping technique of Francis and Kenennberg (1978) [10], CV_i, was employed to group genotypes on the basis of their mean yields and coefficient of variation (CV_i) relative to grand mean and average CV_i. For grain yield, the procedure identified six SC hybrids SC5, SC10, SC11, SC12, SC13, SC16, SC18 and one TWC hybrid TWC24, as most desirable with higher than average yield and smaller than average CV_i (Table 6). Other SC hybrids SC1, SC17, SC14, SC2, SC3, SC9 and check NK-6240 although yielding above average, were judged to be less stable by this procedure because they had larger CV_i. All remaining TWC hybrids except TWC24 and other two checks 30V92 and 900M Gold were considered undesirable because they produced yields below average even though they had small CV_i.

3.2.4 Lin and Binn's Cultivar performance measure (P_i)

Lin and Binns (1988) [19] proposed Cultivar performance measure (P_i) as the mean squares of distance between genotypes i and 'i' where 'i' is the genotype with maximum response over all locations. The smaller the value of Pi, the smaller the distance to the genotype with maximum yield, the better the genotype. Pi values were measured on overall location means and it represents superiority in the sense of general adaptability (wide adaptation). Table 6 presents the cultivar performance measure (P_i) for grain yield of maize. Based on P_i values, SC16 was the most stable genotype followed by SC10, G12, G6 and G9of which G16, G12, G10 and G6 were ranked 1st, 2nd, 3rd and 4th respectively in the grain yield. All TWC hybrids exhibited higher values of Pi, hence they were considered as most unstable genotypes according to this analysis. (Aremu *et al*., 2007b; Lin and Binns, 1988a; Dashiell *et al*., 1994 and Purchase, 1997) [3, 19, 6, 23].

3.2.5 Desirability index (D_i)

Hernandez *et al*. (1993) [12] proposed a desirability index that would combine both yield and regression coefficient. Using both mean yield and b_i can often complicate the breeder's decision when comparing high yielding, less-stable genotypes with low-yielding, stable genotypes. They combined the mean yield and b_i into a unified desirability index (D_i). D_i is equal to the mean of the ith genotype across all environments plus its regression coefficient multiplied by the mean of the environmental indexes of the two extreme environments. Genotypes with high D_i values are desirable. D_i values given in Table 6 indicated that genotypes SC16, SC10, SC12, SC6, SC17 and SC3 had the highest D_i values and were stable with desirable yield performance. None of the TWC hybrids were good according to this procedure. The rank of genotypes for D_i value and mean yield were superimposing to each other (Dehghani *et al*., 2008; Bilgin and Korkut, 2000 and Mohebodini *et al*., 2006) [7, 4, 20]. This procedure is especially useful when breeder encounters with high yielding genotypes having varied non-unity regression coefficients.

3.3 Non-parametric stability measures

Several nonparametric methods proposed by Huhn (1979) are based on the ranks of genotypes in each environment and the idea of homeostasis (environmental resistance) as a measure of the stability. Genotypes with similar rankings across environments are classified as stable. Nonparametric measures for stability based on ranks provide a viable alternative to the above existing parametric measures based on absolute data. For many applications, including selection in breeding and testing programs, the rank orders of the genotypes are the most essential information. Stability measures based on ranks require no statistical assumptions about the distribution of the phenotypic values. They are easy to use and interpret and, compared with parametric measures, are less sensitive to errors of measurement.

3.3.1 Huhn's stability measures (S_i^1 and S_i^2)

Two rank stability measures proposed by Nassar and Huhn (1987) [21] were the statistics S_i^1 which measures the mean absolute rank differences of a genotype over environments and the statistic S_i^2 which shows the variance among the ranks over environments. For a genotype with maximum stability, $S_i^1 = 0$. Similarly, zero variance i.e., $S_i^2 = 0$ also indicates maximum stability. SC hybrids SC19, SC8, SC2, SC16, SC11, SC10 and TWC hybrids TWC22, TWC23 and TWC24 were stable as they recorded lower S_i^1 values.

According to S_i^2 stability measure, SC hybrids SC16, SC19, SC8 and SC10 and TWC hybrids TWC27 followed by TWC22, TWC23 and TWC24were most stable genotypes due to lower values of mean rank variances. It is clearly evident that both Huhn's stability measures S_i^1 and S_i^2 found some worth in TWC hybrids and helped in their selection considering more about consistent and predictable performance across the locations rather than high yield potentiality.

3.3.2 Kang's rank-sum (RS)

This stability combines both cultivar yield and Shukla's stability variance into one statistic. The variety with the highest yield is given a rank of 1, while that of the lowest variance is also assigned a rank of 1. The ranks for yield and variance are summed up. The cultivar having the lowest rank sum is the most stable desirable. According to this method SC hybrids SC16, SC10, SC9, SC13, SC19 and SC18 and one TWC hybrid TWC24 were ranked in the top and considered as most stable and desirable genotypes while SC4, SC20, TWC 26 and check 30V92 were the least stable.

3.4 Spearman rank correlation and comparison of stability parameters

The ranks of 30 genotypes, after applying total eight methods of stability parameters, were used to compute Spearman's rank correlation (Steel & Torrie, 1980) [26] for assessing the relationships among stability parameters and revealed in Table 7. Significant positive rank correlation coefficients were obtained between grain yield and P_i (r = 0.398), D_i (r = 0.987) and Kang's RS (r = 0.645). This result indicated that the use of P_i, D_i and RS as tools to evaluate performance of maize hybrids in future selection programs would favor simultaneous development of stable and very high yielding genotypes like SC hybrids. (Tamane et. al., 2015).

Significant positive rank correlation coefficients were obtained between all possible pairs of S^2d_i, Sh-σ^2, CV_i, S_i^1 and S_i^2 and Kang's RS. The significant positive correlation between these stability parameters suggest that these parameters would play similar roles in stability ranking of genotypes. The regression coefficient bi showed significant positive correlation with Sh-σ^2, S_i^2 and Kang's RS but non-significant positive correlation with S^2d_i, P_i,S_i^1 and RS.

The non-parametric stability parameters S_i^1, S_i^2 and RS showed significant positive correlation with parametric measures like b_i, S^2d_i, Sh-σ^2 and CV_i. This result indicated the close similarity and effectiveness of parametric and non-parametric stability measures in detecting stable maize genotypes across environments. Nonparametric measures for stability based on ranks provided a viable alternative to the existing parametric measures.

Table 7: Spearman's rank correlation between ranks of mean yield and stability parameters

	Mean yield (t/ha)	**b_i**	**S^2d_i**	**Sh-σ^2**	**CV_i**	**P_i**	**D_i**	**Huhn S_i^1**	**Huhn S_i^2**	**Kang's RS**
Mean yield (t/ha)										
b_i	-0.0549									
S^2d_i	-0.0741	0.0714								
Sh-σ^2	-0.1404	0.398*	0.861**							
CV_i	-0.0194	-0.002	0.481*	0.518**						
P_i	0.398*	0.0416	0.0323	-0.0229	-0.0211					
D_i	0.987**	-0.0474	-0.0812	-0.1591	0.417*	0.971**				
Huhn S_i^1	-0.1938	0.443*	0.675**	0.860**	0.460*	-0.0977	-0.1991			
Huhn S_i^2	-0.1969	0.3081	0.719**	0.826**	0.604**	-0.1097	-0.2151	0.808**		
Kang's RS	0.645**	0.2845	0.538**	0.629**	0.417*	0.713**	0.607**	0.479*	0.472*	

Note: b_i: Regression coefficient, S^2d_i: Deviation from regression, Sh-σ^2: Shukla's stability variance,CV_i: Francis and Kannenberg's coefficient of variation, P_i: Lin and Binn's Cultivar performance measure, D_i: Desirability index, S_i^1& S_i^2: Huhn's stability measures, Kang's RS: Kang's rank-sum

3.5 Stability and yield comparisons between single (SC) and three-cross hybrids (TWC)

Mean grain yield and stability values of all 9 stability parameters for both SC and TWC groups were calculated and presented in Table 6. Mean grain yield of 20 SC hybrids (11.81 t/ha) was higher than that of seven TWC hybrids (10.42 t/ha). The b_i values of SC and TWC groups were 1.091 and 0.755, respectively. Lower b_i value indicated that TWC were less responsive to increased levels of inputs, but can perform well under a wide range of marginal environments due to their non-significant S^2d_i value of 0.284. Found that TWCs were aptly suitable for resource poor farmers. SC group showed very good stability due to their unit regression, but they had significant S^2d_i value of 0.829, which indicated that their consistency of performance is less reliable especially when they encountered with less favorable environments. Other stability parameters like Sh-σ^2, Huhn's S_i^1 and S_i^2 had indicated that TWC were more stable than SC. But, as per the values of Lin & binn's cultivar performance measure, desirability index and Kang's rank, it was adjudged that SCs are more favorable hybrids than TWC for reasonably good environments. It was concluded that both SC and TWC are equally desirable for a seed company who want to do business in varied agro-ecological conditions.

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