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G x E interaction and stability analysis in okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract
With prime objective of developing region specific as well as stable variety or hybrids of okra, the present investigation was undertaken with 72 genotypes (11 lines, five testers and their resultant 55 hybrids along with a commercial hybrid check 'OH-102') were sown at three different locations at Navsari Agricultural University, Navsari (Gujarat) in *Kharif* 2018 to obtain the information on stability parameters for fruit yield per plant and its component traits. The stability analysis exhibited significant differences among genotypes (G), environments (E), while genotype x environment interaction was reported non-significant for all traits (except seeds per plant) when tested against pooled deviation indicated that genotypes responded consistently over the environments. Mean square due to genotype x environment interaction (linear) effect was non-significant for all traits (except seeds per plant) indicated that performance of genotypes remained similar for their linear regression on environmental index and significant for seeds per plant indicated that prediction of performance across the environments against these characters would be highly effective. Among locations, Achhalia (E2) was found to be the most favourable for fruit yield and other related traits. Stability analysis for seeds per fruit, revealed that four hybrids viz., AOL-12-52 X Arka Anamika, AOL-12-144 X Parbhani Kranti, AOL-14-32 X Parbhani Kranti and AOL-14-32 X Arka Abhay manifested below average stability, indicated that hybrids specifically adapted to favorable (good) environments while hybrid AOL-12-52 X GJO-3 manifested above average stability, indicated that this hybrid specifically adapted to unfavorable (poor) environments.

Keywords: Okra, G x E interaction, environments and stability

Introduction
Vegetable crops offer higher yield, income and calories as compared to agronomical crops, hence vegetable farming has become profitable enterprise. Okra (*Abelmoschus esculentus* [L.] Moench) is an annual vegetable crop grown in tropical and subtropical regions of the world. It is quite popular in India because of easy cultivation, dependable yield and adaptability to varying moisture conditions. Performance of various okra genotypes keeps varying in varying environmental conditions. The phenomenon of genotype x environment interaction is a common problem in plant breeding program and has long been a challenge to plant breeder. A variety developed by a plant breeder is usually grown at different locations for many years under different conditions. The occurrence of G x E interactions had created a major challenge in obtaining a complete understanding of genetic control of the variability. This has posed a serious problem in interpreting evolutionary trends and hampered the rationalization of policy and procedure in breeding for improved performance in economically important crops. Phenotypic stability may be influenced by the allelic balance of genotypes which results in the ability of the genotypes to buffer against the environmental changes. The genotypic and environmental interactions are usually present under all conditions in purelines, hybrids, synthetics or any other material used for breeding which complicate the breeding work and forbid the progress of the crop improvement programmes (Eberhart and Russell, 1966) [4]. Assessing any genotype without including its interaction is incomplete and thus limits the accuracy of yield estimates. It is usually preferable to estimate yield stability and reliability values with reference to all genotype x environment interaction effects (Ezekiel *et al.*, 2011) [5]. Thus, it is imperative to study the performance of a crop in more than one environment to identify genotypes, which give high stability for various yield related traits over a wide range of environment (Jindal *et al.*, 2008) [8]. Thus, in plant breeding programme, many potential genotypes are usually evaluated in different environments by conducting evaluation trials at different locations and over different years before selecting desirable genotypes. Therefore,

breeding efforts are directed towards stepping up the yield levels through the development of high yielding varieties and hybrids for different environment. Hence, there is a need for development of environment (location) specific hybrids in addition to identification of stable hybrids over environments.

Material and Methods

The experimental material for the study comprised consisting of 11 lines, five testers and their resultant 55 hybrids along with a commercial hybrid check 'OH-102' of okra was laid out in a randomized block design with three replications over in three different locations *viz;* College farm, NMCA, Navsari (E_1)**,** Cotton Research Sub Station, Achhalia (E_2) and Regional Rice Research Station, Vyara (E_3) in NAU, Navsari during *kharif* 2018. Observations on 16 traits were recorded for each individual location. Each grnotype was sown in a single row of ten plants, spaced 60 x 30 cm. The statistical analysis for genotype x environment interaction and stability was carried out according to Eberhart and Russell (1966) [4] for fruit yield and its component traits in okra.

Results and Discussion

In the present study, the approach suggested by Eberhart and Russell (1966) [4] has been employed to understand the differential G x E interaction of parents and hybrids to access the stability of individual genotypes. The results revealed (Table 1) that variance due to genotypes were significant for all traits when tested against pooled error indicated that sufficient variability present among genotype. The variance due to environments significant for all traits when tested against pooled error (except fruit diameter and fiber content) and pooled deviation (except fruit diameter, fiber content and 100 seed weight) which indicated that, environments were effective in influencing the performance of the genotypes. The genotype x environment interaction components were also found significant for the all the traits when tested against pooled error (except fruit weight) which satisfied the requirements of stability analysis. The genotype x environment interactions was reported non-significant for all traits under studied (except seeds per fruit), when tested against the pooled deviation. The lack of significant G x E interaction of the traits under study indicated that genotypes responded consistently over the environments, so there is no need to study further for these traits. Similar finding reported by Patel (1985) [16], Jindal *et al.* (2008) [8], Patel (2012) [15], More (2015) [12] and More *et al.* (2018) [13]. The trait seed per fruit found significant against G x E interaction when tested against pooled deviation, suggesting differential reaction of genotypes to varied environments. Therefore, the genotypes must be tested over extensive range of environments for proper assessment, were these are to be ultimately grown for commercial purposes. Significant mean squares due to E + (G x E) were also observed for all these traits when tested against pooled error revealed that, the genotypes interacted significantly with the environments. Similar result was reported by Mishra and Chhonkar (1919) [11], Poshiya and Vashi (1997) [17], Ariyo and Vaughan (2000) [2], Jindal *et al.* (2008) [8], Javia (2014) [7] and More *et al.* (2018) [13] in okra with different set of genotypes. The mean squares due to environments (linear) were highly significant for all the traits except fruit diameter, stalk length, 100 seed weight and fiber content when tested against pooled deviation. However, the same was significant for all the traits when tested against pooled error. This indicated that variation among environments was linear and it signifies unit change in environmental index for each unit change in the environmental conditions.

The variance due to G x E were further partitioned in to components (i) G x E (linear) and (ii) G x E (non-linear) i.e. pooled deviation. Mean square due to genotype x environment interaction (linear) effect was non- significant for all traits under studied, only one trait seeds per fruit exhibited significant when tested against pooled deviations. Conclusion is drawn that variation in the performance of genotype for these trait is due to the regression of genotype on environments and it suggested that the prediction of performance across the environments against these characters would be highly effective. Remaining all traits showed non-significant response with G x E interaction (linear) effect, suggested that performance of genotypes remained similar for their linear regression on environmental index. The non-significant mean square due to G x E rest of all traits, indicated that these traits are not, therefore, included in the further study. These finding were confirmed with result of the Patel (1985) [16], Patel (2012) [15], More (2015) [12] and More *et al.* (2018) [13]. The mean squares due to pooled deviation were found to be significant for all the traits (except fruit weight and number of seeds) which suggested that the prediction of performance of genotypes over environment based on regression analysis for these traits might not be very reliable and lack of possibilities to predict the performance of genotype across the environments for these characters. These results are in accordance with the earlier findings of Ariyo (1990) [1], Gondane and Lai (1993) [6], Poshiya and Vashi (1997) [17], Jindal *et al.* (2008) [8] and More *et al.* (2018) [13].

The estimates of environmental indices revealed (Table 2) that the traits like days to 50% flowering, plant height, days to first picking, days to last picking, fruit weight and fiber content were performed better at Navsari. The important traits like internodal length, branches per plant, fruit length, stalk length, seeds per plant, 100 seed weight and fruit yield per plant were more favoured at Achhalia. While traits like first flowering node, fruits per plant, fruit diameter and 100 seed weigh were more favoured at Vyara. In general, the environment Achhalia (E_2) was found to be the most favourable for fruit yield and other related traits.

According to Eberhart and Russell (1966) [4], an ideal variety would be one that possessed high mean performance (of course greater than population mean), unit regression coefficient (bi = 1) and least deviation from regression *i.e.*, as far as possible equal to zero (S^2di = 0). Result of stability parameters of 72 genotypes revealed that none of the genotype was stable for all the traits studied. Similar results were reported by Jindal *et al.* (2009) [9], Dabhi *et al*., (2010) [3], Kachhadia *et al.* (2011) [10], Senthilkumar (2011) [19], Patil (2013), Yadav *et al.* (2013) [20], Javia (2014) [7], Namita *et al.* (2014), More (2015) [12], Prakash *et al.* (2017) [18] and More *et al.* (2018) [13]. Thus, any generalization regarding stability of genotypes for all the traits is too difficult since the genotype may not simultaneously exhibit uniform responsiveness and stability patterns for all these traits. Stability performance is one of the most desirable properties of a genotype for its wide adaptation. For seeds per fruit based on the stability parameters [mean performance (lower mean value is desirable for seeds per fruit), regression coefficient (bi) and individual squared deviation from linear regression (S^2_{di})] four hybrids *viz.*, AOL-12-52 X Arka Anamika, AOL-12-144 X Parbhani Kranti, AOL-14-32 X Parbhani Kranti and AOL-14-32 X Arka Abhay manifested mean value in desirable direction along with non-significant bi value higher than unity and non-significant S^2_{di} value with least deviation, indicated that hybrids specifically adapted to favorable (good) environments. Only one hybrid AOL-12-52 X GJO-3 manifested mean value in desirable direction along with non-significant bi value lesser than unity and non-significant S^2_{di} value with least deviation, indicated that this hybrid specifically adapted to unfavorable (poor) environments.

The chance for selection of stable genotypes could be strengthened by selection in favour of stability in some yield component. The mean yield of each genotype depends on the particular set of environmental conditions. It is therefore, suggested that in order to identify stable genotype, actual testing over a wide range of environments including poor and good ones would be advantageous while making selection and attention should be paid to the phenotypic stability of traits directly related to fruit yield, particularly fruits per plant, fruit weight, branches per plant, plant height and inter nodal length so as to achieve maximum stability for the end product *i.e.*, fruit yield in okra. But in present investigation yield contributing traits and other all traits also reported as consistence performance in stability analysis, which showed lack of association to achieve maximum stability for fruit yield in okra.

Table 1: Analysis of variance for phenotypic stability pertaining to various traits in okra

Source	DF	Traits							
		Days to 50% flowering	**First flowering node**	**Inter nodal length (cm)**	**Branches per plant**	**Fruits per plant**	**plant height (cm)**	**Days to first picking**	**Days to last picking**
Genotypes (G)	71	10.997 **	0.398**	0.896**	0.227**+	25.707**++	165.540**+	9.315**	8.111**
Environments (E)	2	172.838**++	9.563**++	40.237**++	16.574**++	65.004**++	5472.845**++	199.930**++	87.320**++
G x E	142	8.700**	0.306**	0.654**	0.147**	2.874**	105.918**	7.751**	8.684**
Environment (E) + (G x E)	144	10.979**	0.435**+	1.204**++	0.376**++	3.737**	180.458**+	10.421**+	9.776**
Environment (linear)	1	345.676**++	19.127**++	80.474**++	33.148**++	130.008**++	10945.690**++	399.859**++	174.641**++
G x E (linear)	71	8.764**	0.32**	0.634**	0.157**	2.822**	98.977**	8.347**	9.474**
Pooled deviation	72	8.516**	0.288**	0.665**	0.136**	2.886**	111.291**	7.057**	7.785**
Pooled error	426	2.043	0.114	0.207	0.038	1.108	33.520	2.140	3.828
Source	**DF**	**Traits**							
		Fruit length (cm)	**Fruit diameter (cm)**	**Stalk length (cm)**	**Fruit weight (g)**	**Seeds per fruit**	**100 seed weight (g)**	**Fruit yield per plant (g)**	**Fiber Content (%)**
Genotypes (G)	71	1.446**	0.006**	0.014**	2.767**++	31.602**++	0.245**++	3876.256**++	0.169**
Environments (E)	2	80.154**++	0.009	0.044**+	160.871**++	61.986**++	0.362*	17734.249**++	0.002
G x E	142	1.339**	0.008**	0.012**	0.557	12.731**++	0.140**	498.401**	0.101**
Environment (E) + (G x E)	144	2.433**+	0.008**	0.012**	2.784**++	13.415**++	0.144**	737.788**+	0.992**
Environment (linear)	1	160.308**++	0.018	0.087**+	321.741**++	123.972**++	0.723**+	35468.497**++	0.005
G x E (linear)	71	1.054**	0.007**	0.011**	0.614	23.915**++	0.147**	523.607**	0.076**
Pooled deviation	72	1.600**	0.009**	0.013**	0.494	1.524	0.132*	466.623**	0.123**
Pooled error	426	0.293	0.003	0.004	0.790	7.727	0.094	217.581	0.028

*, ** Significant at 5 % and 1 % level, respectively against pooled error.
+, ++ Significant at 5 % and 1 % level, respectively against pooled deviation

Table 2: Estimates of environmental index for various traits under different environments in okra

Sr. No.	Traits	Environmental index		
		E_1 Navsari	**E_2 Achhalia**	**E_3 Vyara**
1.	Days to 50% flowering	-1.66	0.25	1.41
2.	First flowering node	0.10	0.31	-0.40
3.	Inter nodal length (cm)	-0.23	-0.61	0.84
4.	Branches per plant	0.25	0.30	-0.55
5.	Fruits per plant	-0.87	-0.14	1.01
6.	plant height (cm)	6.79	3.04	-9.83
7.	Days to first picking	-1.52	-0.26	1.78
8.	Days to last picking	1.15	-0.11	-1.05
9.	Fruit length (cm)	0.19	0.95	-1.14
10.	Fruit diameter (cm)	-0.01	0.00	0.01
11.	Stalk length (cm)	0.03	-0.02	0.00
12.	Fruit weight (g)	1.16	0.52	-1.69
13.	Seeds per fruit	0.49	-1.07	0.58
14.	100 seed weight (g)	0.08	-0.03	-0.05
15.	Fruit yield per plant (g)	8.675	9.442	-18.117
16.	Fiber content (%)	-0.01	0.01	0.00

Table 3: Stability parameters for seeds per fruit for parents and hybrids in okra

Sr. No.	Genotypes	Seeds per fruit			Sr. No.	Genotypes	Seeds per fruit		
		Mean	**b_i**	**S^2_{di}**			**Mean**	**b_i**	**S^2_{di}**
	Parents					**Hybrids**			
	Females (Lines)				36	AOL-12-144 X Arka Abhay	49.82	1.95	-7.70
1	AOL-12-52	52.84	0.66	-7.72	37	AOL-12-133 X GJO-3	41.82	-2.15*	-7.70
2	AOL-12-59	42.00	-0.98	-6.47	38	AOL-12-133 X GAO-5	39.31	2.35	-4.71
3	AOL-13-73	49.73	-2.86*	-7.68	39	AOL-12-133 X Parbhani Kranti	43.02	-4.27*	-7.64
4	AOL-12-144	42.96	-6.66*	-7.46	40	AOL-12-133 X Arka Anamika	45.20	-2.61*	-7.69

5	AOL-12-133	48.00	-0.37**	-7.72	41	AOL-12-133 X Arka Abhay	47.29	-1.04*	-7.71
6	AOL-14-32	53.91	2.53	-7.69	42	AOL-14-32 X GJO-3	46.22	4.61	7.04
7	JOL-69-05	47.73	2.96	-2.34	43	AOL-14-32 X GAO-5	46.27	0.50*	-7.72
8	JOL-11-12	42.93	-1.67	-7.60	44	AOL-14-32 X Parbhani Kranti	42.19	1.41	-3.59
9	JOL-13-05	50.27	3.36*	-7.67	45	AOL-14-32 X Arka Anamika	45.20	-4.85*	-7.62
10	JOL-14-10	41.22	-0.56	-6.24	46	AOL-14-32 X Arka Abhay	42.73	1.44	-4.50
11	JDNOL-11-12	41.40	-2.86*	-7.68	47	JOL-69-05 X GJO-3	41.78	3.57	-3.21
	Males (Testers)				48	JOL-69-05 X GAO-5	42.56	2.50	-6.15
12	GJO-3	46.47	-1.85	-2.68	49	JOL-69-05 X Parbhani Kranti	47.64	5.74	-7.07
13	GAO-5	46.18	6.13*	-7.56	50	JOL-69-05 X Arka Anamika	42.58	2.56	-1.33
14	Parbhani Kranti	45.89	5.05*	-7.61	51	JOL-69-05 X Arka Abhay	49.49	3.74	-6.35
15	Arka Anamika	41.84	-9.03*	-7.37	52	JOL-11-12 X GJO-3	45.22	1.57	-7.71
16	Arka Abhay	40.82	0.46*	-7.72	53	JOL-11-12 X GAO-5	41.87	-2.91	0.56
	Parental mean	45.89			54	JOL-11-12 X Parbhani Kranti	48.02	-0.17**	-7.72
	Hybrids				55	JOL-11-12 X Arka Anamika	45.69	3.70	-5.69
17	AOL-12-52 X GJO-3	44.16	0.69	-6.43	56	JOL-11-12 X Arka Abhay	45.91	6.79*	-7.47
18	AOL-12-52 X GAO-5	44.33	7.08*	-7.50	57	JOL-13-05 X GJO-3	44.91	0.38	-2.27
19	AOL-12-52 X Parbhani Kranti	43.33	3.48*	-7.67	58	JOL-13-05 X GAO-5	43.42	3.81*	-7.66
20	AOL-12-52 X Arka Anamika	43.02	1.33	-7.71	59	JOL-13-05 X Parbhani Kranti	41.22	-3.41	-5.75
21	AOL-12-52 X Arka Abhay	50.73	4.67	-5.22	60	JOL-13-05 X Arka Anamika	42.00	0.12**	-7.72
22	AOL-12-59 X GJO-3	38.09	-0.04**	-7.72	61	JOL-13-05 X Arka Abhay	43.42	-1.00	-7.31
23	AOL-12-59 X GAO-5	42.16	3.88	-4.93	62	JOL-14-10 X GJO-3	43.42	1.82	-5.37
24	AOL-12-59 X Parbhani Kranti	45.07	1.28	-1.41	63	JOL-14-10 X GAO-5	43.91	4.75	-6.96
25	AOL-12-59 X Arka Anamika	47.16	-0.40	-6.39	64	JOL-14-10 X Parbhani Kranti	44.78	2.78*	-7.69
26	AOL-12-59 X Arka Abhay	43.89	-5.08	-4.66	65	JOL-14-10 X Arka Anamika	46.53	5.34*	-7.60
27	AOL-13-73 X GJO-3	42.78	-0.79	-2.39	66	JOL-14-10 X Arka Abhay	44.49	5.29	-7.02
28	AOL-13-73 X GAO-5	46.13	2.73	-7.69	67	JDNOL-11-12 X GJO-3	47.62	9.90*	-7.30
29	AOL-13-73 X Parbhani Kranti	48.13	-2.82	-2.99	68	JDNOL-11-12 X GAO-5	50.49	1.45	-7.71
30	AOL-13-73 X Arka Anamika	41.67	-4.85*	-7.62	69	JDNOL-11-12 X Parbhani Kranti	44.38	3.93	-7.25
31	AOL-13-73 X Arka Abhay	43.47	0.09	-6.82	70	JDNOL-11-12 X Arka Anamika	43.56	0.33*	-7.72
32	AOL-12-144 X GJO-3	48.67	-1.74*	-7.71	71	JDNOL-11-12 X Arka Abhay	49.40	9.94*	-7.29
33	AOL-12-144 X GAO-5	52.29	-1.16*	-7.71		Hybrid mean	44.85		
34	AOL-12-144 X Parbhani Kranti	42.20	1.58	-6.62	72	Check (OH-102)	43.42	-7.21	-5.71
35	AOL-12-144 X Arka Anamika	46.07	5.10*	-7.61		General Mean	45.06		

*, ** significant at 5 per cent and 1 per cent of probability levels, respectively.

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