Biological Forum – An International Journal 15(2): 1185-1194(2023)

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Insights into Phenotypic Stability of Okra [*Abelmoschus esculentus* (L.) Moench] Hybrids Evaluated under Multi Environments

A.A. Patel[1], R.D. Vekariya[2], A.I. Patel[3] and A.G. Singh[1]*
[1]Department of Genetics and Plant Breeding,
N.M. College of Agriculture, Navsari Agricultural University, Navsari (Gujarat), India.
[2]Wheat Research Station, Navsari Agricultural University, Bardoli (Gujarat), India.
[3]Department of Vegetable Science, ACHF, NAU, Navsari (Gujarat), India.

(Corresponding author: A.A. Patel)*
(Received: 01 January 2023; Revised: 13 February 2023; Accepted: 17 February 2023; Published: 22 February 2023)
(Published by Research Trend)

ABSTRACT: Stability analysis is an important tool for plant breeders where they study g × e interaction on yield and its attributes by growing a genotype at different locations/seasons for many years to identify stable and high-yielding genotypes under a wide range of environments. The present investigation comprising 35 genotypes was carried out to evaluate them in four different environments at Navsari Agricultural University. The experimental material consisted of 35 genotypes; representing 24 hybrids developed by line × tester mating of 10 diverse parents and commercial hybrid check 'OH-102'. Analysis of variance for stability revealed that the genotypes and environments showed highly significant differences for all the characters when tested against both, pooled error and pooled deviation. The differences due to genotype × environment interaction were significant to highly significant when tested against pooled deviation for the characters like average fruit girth, average fruit weight, plant height at final harvest, branches/plant at final harvest, internodes/plant at final harvest, fruits/plant and fruit yield/plant. None of the parent or hybrid was found consistently stable for all the characters but the parent GAO-5 and the hybrids AOL-16-04 × Arka Anamika, AOL-16-04 × Arka Abhay, AOL-16-04 × Kashi Kranti, AOL-16-04 × Parbhani Kranti and NOL 17-06 × Arka Anamika exhibited average stability for fruit yield/plant. Whereas, hybrid NOL 17-05 × Arka Anamika and NOL 17-09 × Arka Anamika exhibited below-average stability. Such hybrids could be utilized as environment-specific hybrids. These hybrids could also be used as breeding stock for incorporation in crosses with the objective of improving economic traits.

Keywords: Okra, stability, fruit yield, environments.

INTRODUCTION

Okra [*Abelmoschus esculentus* (L.) Moench], a well-known vegetable crop is cultivated in several zones of the tropical, sub-tropical basal altitudinal Asian, African, American, and temperate regions of the Mediterranean basin. At the global forum, India is a key okra producer consisting of 72 percent of the total area largely in the states of Gujarat, Maharashtra, Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Karnataka, Haryana, and Punjab both as *kharif* and summer season crop (Anonymous, 2017). Land under okra cultivation comprises 25.32 ('000 ha) with an annual production of 105.49 (000) tonnes and a productivity of 4.17 t/ha (FAOSTAT, 2020). According to de Candolle (1883), the probable centers of origin for okra might be Ethiopia (Abyssinian region) and West Africa. However, it is also believed to be originated in the Hindustani center of origin, of which chiefly in India (Zeven and Zhukovsky 1975). Taxonomically okra is classified under the family Malvaceae and genus *Abelmoschus* having nine different species with diploid chromosome numbers varying from 56 to 196 and having a genome size of 3897 Mbp to 17321 Mbp. The most common species, *A. esculentus*, is an amphidiploid (29T + 36Y) having 2n = 130 chromosomes. Due to its short life span, rapid growth, and photo-insensitive nature, farmers usually raise okra in both seasons. In comparison to other vegetables, it has higher nutritive value and extended shelf life, therefore it occupies the topmost position in the list of commercial vegetable crops meant to be exported as it shares approximately 60 percent of the total export of fresh vegetables (Varmudy, 2000). However, less effective yield open-pollinated varieties, the uncertainty of high-yielding varieties/hybrids to produce the same yield at every location, and poor resistivity for pests and diseases like fruit and shoot borer, okra yellow vein mosaic virus (YVMV), and enation leaf curl virus

(ELCV) are the chief reasons to lower the productivity in India (Patel *et al.,* 2020). In spite of the numerous advantages of available open-pollinated varieties (OPVs), the importance of hybrid varieties (F_1 hybrids) has recently been pointed out by farmers, scientists, and technologists in developing countries. F_1 hybrids have more vigor, higher yield and quality, production stability, suitability to high input agriculture, shorter life cycle, uniform growth and maturity, and greater disease resistance than many of the open-pollinated varieties. In view of this crop's potentiality, there is a need for its improvement through the development of varieties and hybrids suitable to specific agro-climatic zones (Vekariya *et al*., 2020).

In any plant breeding programme, once superior recombination is achieved, the next important step is to check their performance over different environments. The observed morphogenic variation is being composite of three variables, *viz*., genetic expression, environmental, and genotype × environment interaction being subject to modification by the environment; the genotypic expression of the phenotype is environmentally dependent (Kang, 1998). Genotype × Environment (GE) interaction is valuable for explaining adaptation patterns and may be used by selecting for explicit adaptation or by creating deliberately adapted genotypes (Ummyiah *et al*., 2021; Singh and Shukla 2022).

To prevent genetic vulnerability brought on by a shrinking of any crop's genetic basis the interactions of the germplasm are essential (Kang, 1998; Ummyiah *et al*., 2021).

The interaction between genotype and environment continues to be a significant barrier to the consistent output of selected genotypes, despite iterative selection and thorough evaluation. Now, the corresponding ranks of genotypes change with the change in environments, which makes it difficult for plant breeders to properly evaluate genotypes and provide a trustworthy estimate of heritability. Additionally, it becomes more challenging to forecast with better accuracy the rate of genetic progress while selecting any character. Because of the large interplay between genotypes and surroundings, progress due to selection is slowed (Comstock and Moll 1963). For the selection or recommendation of newer genotypes in any plant breeding programme, the stable performance for economical characters is an utmost necessity. Henceforth, growing breeding lines over time and space has become a core part of any crop improvement programme. While deciding on breeding methods and performing selection programme in crops, knowledge of nature and the virtual magnitude of genotype x environment interaction is essential (Baker, 1969). Environment stratification has been used to reduce the interaction between genotypes and surroundings and to improve selection accuracy. Nevertheless, despite technological improvement, very high interaction between genotypes and environments within the same year still exists (Allard and Bradshaw 1964). Sprague (1966) said that despite awareness of the variables causing such interactions, it is doubtful if genotype x environment (G × E) interactions can be reduced in field trials. It aids in identifying genotypes that exhibit high stability for numerous yield-related variables under a variety of environmental conditions. The use of such stable genotypes for general cultivation over a wide range of environmental conditions helps in achieving stabilization of crop production over locations and years. Therefore, it is necessary to study the stability of okra genotypes in relation to the environment and it forms an important step before the release of any variety or hybrid.

MATERIAL AND METHODS

At the College farm of N. M. College of Agriculture, Navsari Agricultural University, Navsari, the present experiment was conducted. Geographically, Navsari is situated in the region of south Gujarat at 20°-37' N latitude and 72°-54' E longitude and an altitude of 11.98 meters above the mean sea level. The weather during the growing season was normal and favorable for crop growth. The experimental material consisted of 35 genotypes; representing 24 hybrids developed in line x tester mating of 10 diverse parents (six lines *viz.,* GAO-5, GO-6, AOL-16-04, NOL 17-05, NOL 17-06, NOL 17-09 and four testers *viz*., Arka Anamika, Arka Abhay, Kashi Kranti, and Parbhani Kranti) and commercial hybrid check 'OH-102'. Hand emasculation and pollination technique was used for the development of all hybrids. Plantings done in the summer (January), late summer (February), *kharif* (June), and late *kharif* (July) created four different environments (Table 1) for genotype evaluation. All the genotypes were evaluated in Randomized Complete Block Design (RBD) and replicated thrice. The field representation of each genotype comprised a single-row plot of ten plants, spaced at 45 x 30 cm during summer and 60 × 30 cm during *kharif*. Observations were recorded on 13 characters *viz*., days to 50 % flowering, days to first picking, days to last picking, average fruit length, average fruit girth, average fruit weight, plant height at final harvest, branches/plant at final harvest, internodes/plant at final harvest, internodal length at final harvest, fruits/plant, fruit yield/plant and fiber content. The Eberhart and Russell (1966) model was utilized to study the G x E interaction of different genotypes and to understand the stability of individual genotypes.

Table 1: Details of environments under which the genotypes were evaluated.

Environment	Location	Season	Date of sowing	Rainfall (mm)	Sunshine (h)
E_1	Navsari	Summer	15-01-2019	0.00	8.30
E_2	Navsari	Late summer	15-02-2019	0.00	8.30
E_3	Navsari	*Kharif*	01-06-2019	262.0	6.10
E_4	Navsari	Late *kharif*	01-07-2019	491.0	2.30

RESULTS AND DISCUSSION

ANOVA for phenotypic stability. The analysis of variance for genotype × environment interaction of 13 characters is presented in Table 2. With the exception of days to first picking, the variance attributable to genotype was significant for all characteristics, indicating the presence of considerable diversity in the material under study. The study also showed that the imposed environments for each character varied significantly (except fiber content). Similar results were reported by More *et al.* (2018); Vekariya *et al.* (2019).

The significance of genotypes × environment interactions when tested against pooled error, exhibited significance for all the traits, which meant that each genotype and environment have a considerable impact on each other. The G × E interactions for various plant growth characters and yield in okra have also been reported by More *et al.* (2018); Vekariya *et al.* (2019) as significant. The genotype x environment interactions when tested against pooled deviation, were significant for seven characters *viz.*, average fruit girth, average fruit weight, plant height at final harvest, branches/plant at final harvest, internodes/plant at final harvest, fruits/plant and fruit yield/plant. The non-significant G x E interaction for the remaining traits suggested a consistent response of genotypes over the environments for these traits and therefore their results are not included in the study.

The mean squares due to E + (G × E) were also significant for all these seven traits when tested against pooled error and pooled deviations, Thus, the necessities of stability analysis against pooled error were satisfied and it was further partitioned into three components i) Environments (Linear) ii) G × E (Linear) and iii) Pooled deviation (G × E; Non-linear).

Table 2: Analysis of variance for phenotypic stability pertaining to various traits in okra.

Sr. No.	Characters	Mean sum of sqaures							
		Genotypes (G)	Environment (E)	Genotype x Environment (G x E)	E + (G x E)	Environments (linear)	G x E (linear)	Pooled deviation	Pooled error
	df	34	3	102	105	1	34	70	272
1	Days to 50 % flowering	8.98**+	369.75**++	4.67**	15.10**++	1109.24**++	3.79**	4.96**	1.60
2	Days to first picking	8.93	671.56**++	5.37**	24.40**++	2014.68*++	4.19**	5.78**	2.04
3	Days to last picking	23.01**++	4202.65**++	11.33**	131.09**++	12607.96*++	12.76**	10.32**	5.35
4	Average fruit length	1.24**++	59.39**++	0.61*	2.29**++	178.17*++	0.75*	0.52	0.43
5	Average fruit girth	0.28**++	0.86**++	0.09**++	0.11**++	2.59*++	0.22**++	0.03**	0.01
6	Average fruit weight	1.78**++	59.19**++	0.78**+	2.44**++	177.57*++	1.22**++	0.54*	0.34
7	Plant height at final harvest	123.47**++	42616.03**++	58.83**++	1274.75**++	127848.09*++	119.07**++	27.89	28.95
8	Branches/plant at final harvest	0.66**++	12.96**++	0.15**+	0.52**++	38.88*++	0.26**++	0.10**	0.01
9	Internodes/plant at final harvest	3.54**++	499.12**++	0.80+	15.04**++	1497.35*++	1.34**++	0.52	0.64
10	Internodal length at final harvest	1.10**++	41.56**++	0.39**	1.56**++	124.69*++	0.28	0.42**	0.18
11	Fruits/plant	3.07**++	553.73**++	1.10**+	16.89**++	1661.18*++	1.75**++	0.75	0.62
12	Fruit yield/plant	1106.08**++	106667.27**++	322.43**++	3360.85**++	320001.80*++	615.94**++	170.65*	123.35
13	Fiber content (%)	0.17**++	0.02	0.03**	0.03**	0.06	0.02	0.03**	0.02

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

Environments varied significantly across different sowing dates and produced ecosystems, according to the mean square due to the environments (linear) component with high significance for all seven features. Similar results have been reported by More *et al.* (2018); Vekariya *et al.* (2019). All seven characters' mean square values for the G × E (linear) regression were found to be significant, indicating that the values for each regression line were statistically different and that the variation in genotype performance was caused by genotype regression on environmental indices, and as a result, genotype performance would be predictable. However, the average fruit girth, average fruit weight, branches/plant at final harvest, and fruit yield/plant mean square values due to G x E (pooled deviation) were significant, suggesting that the prediction of genotype performance over environment based on regression analysis might not be very trustworthy and that there were few opportunities to visualize the performance of genotypes across the environments. These results are in accordance with the earlier findings of More *et al.* (2018); Vekariya *et al.* (2019).

If a genotype performs predictably or not depends on the relative amplitude of the linear and non-linear components of the G × E interaction. The significance of both linear and non-linear (pooled deviation) components of the G × E interaction emphasized the need for consideration of the magnitude of both components. The linearity in the reaction of genotypes to environmental index was the result of a larger magnitude of linear component [G × E (L)* > G x E (NL)*] and hence prediction of the performance of genotypes over environments as possible. In accordance, linear responses of three kinds of (bi) *viz.*, bi < 1, bi = 1, and bi > 1 are interpreted as bi = 1 with average stability is widely adapted to different environments; bi > 1 and significant with below average stability shows sensitivity to environmental changes and is well adapted to a favorable environment, while bi < 1 and the significant with the above average stability shows greater tolerance to environmental changes and hence the genotype would have specific adaptability to poor environment.

With the above requirements and limitations, only seven characters *viz.*, average fruit girth, average fruit weight, plant height at final harvest, branches/plant at final harvest, internodes/plant at final harvest, fruits/plant and, fruit yield/plant were analyzed for stability parameters. For the identification of stable genotypes, high or low mean values than the population mean as per the economic importance of character, a regression coefficient (b_i) equals to unity and its significant deviation from unity and a mean square deviation from linear regression coefficient statistically equal to zero (S^2di) were employed

Environmental Index (Ij). The estimated environmental index for 13 different characters in okra is presented in Table 3. The environmental index was observed to be congenial for days to 50% flowering, days to first picking in E_1. While it was favourable for days to last picking, average fruit length, average fruit girth, plant height at final harvest, branches/plant at final harvest, internodes/plant at final harvest, fruits/plant and fruit yield/plant in E_3. It was favourable for fruit weight in E_4. It was favourable for internodal length at final harvest and fiber content in E_2. Looking at overall performance, E_3 environment is best for the genotypes which were grown under this environment against E_1, E_2, and E_4.

Table 3: Environmental index estimates of all traits in okra under diverse environments.

Sr. No.	Traits	Environmental index			
		E_1	E_2	E_3	E_4
1	Days to 50 % flowering	-2.881	-2.748	2.852	2.776
2	Days to first picking	-3.883	-3.702	3.755	3.831
3	Days to last picking	3.648	-14.352	11.819	-1.114
4	Average fruit length	-1.27	-0.977	1.154	1.092
5	Average fruit girth	-0.125	-0.133	0.189	0.069
6	Average fruit weight	-1.231	-1.016	1.084	1.163
7	Plant height at final harvest	-14.527	-28.724	50.62	-7.369
8	Branches/plant at final harvest	-0.685	-0.332	0.594	0.423
9	Internodes/plant at final harvest	-2.034	-2.967	5.445	-0.443
10	Internodal length at final harvest	0.119	-1.423	1.233	0.072
11	Fruits/ plant	-1.946	-3.328	5.694	-0.42
12	Fruit yield/ plant	-33.363	-48.52	75.024	6.859
13	Fiber content (%)	0.014	-0.024	-0.015	0.026

Stability Parameters. For the widespread cultivation of any genotype, the foremost need is its stability. To evaluate the correlative stability of 35 different genotypes for 13 different characters in okra, the stability parameters were determined as per Eberhart and Russell's (1966) model. The results are presented in Table 4-6. For a genotype to be considered stable and adaptable to varied environmental conditions, it must have superior mean values, regression coefficient value of unity (bi = 1), and non-significant deviation from linear regression ($S^2di = 0$). Nonetheless, the genotype was considered responsive and suitable for favourable environmental conditions when it has a higher mean value and value of regression coefficient more than unity with non-significant deviation from linear regression. Additionally, the genotype was considered to be responsive and suitable for poor environmental conditions when it has higher mean values and regression coefficient less than unity or negative and non-significant deviations from linear regression. Hence, the classification of genotypes was made as per their suitability to diverse environmental conditions.

Table 4: Stability parameters for average fruit girth, average fruit weight and plant height at final harvest of parents and hybrids in okra.

Sr. No.	Genotypes	Average fruit girth			Average fruit weight			Plant height at final harvest		
		Mean	b_i	Mean	Mean	b_i	S^2_{di}	Mean	b_i	S^2_{di}
	PARENTS									
	FEMALES (LINES)									
1	GAO-5	1.53	1.57	0.02*	10.02	1.53*	-0.32	86.70	0.74*	5.70
2	GO-6	1.46	1.34	0.07**	9.89	1.85	2.46**	84.35	0.70	-14.86
3	AOL-16-04	1.56	1.09	0.07**	9.92	0.71	0.23	95.51	1.01	8.37
4	NOL 17-05	1.74	2.30	0.04**	10.15	1.87**	-0.31	93.00	0.79	33.59
5	NOL 17-06	1.43	0.15	0.01	9.64	0.89	0.07	80.16	0.84	15.67
6	NOL 17-09	1.77	1.11	0.02*	10.24	0.73	-0.19	75.61	0.82	-18.23
	MALES (TESTERS)									
7	Arka Anamika	1.44	0.18	0.00	10.00	0.47	0.24	89.48	0.85	-13.18
8	Arka Abhay	1.45	0.91	0.05**	9.45	0.13	-0.13	91.85	0.84	-3.33
9	Kashi Kranti	1.41	-0.36	0.01	9.48	0.58	-0.19	84.66	0.87*	-28.14
10	Parbhani Kranti	1.42	0.70	0.00	10.02	0.70	-0.19	83.71	0.68	6.15
	Parental mean	1.52			9.88			86.50		
	HYBRIDS									
11	GAO-5 × Arka Anamika	1.31	-0.34*	0.00	10.70	0.83	0.20	92.51	0.80*	-23.77
12	GAO-5 × Arka Abhay	1.40	-0.23	0.00	10.30	0.55	-0.22	98.51	1.06	-25.23
13	GAO-5 × Kashi Kranti	1.37	-0.61*	0.00	9.26	0.88	-0.23	95.06	1.23*	-24.82
14	GAO-5 × Parbhani Kranti	1.27	-0.26	0.00	9.87	0.58	-0.08	92.76	0.99	-24.54
15	GO-6 × Arka Anamika	1.33	-0.22*	0.00	9.87	0.15*	-0.28	93.24	1.14	-8.43
16	GO-6 × Arka Abhay	1.33	0.22	0.01	10.01	1.45	0.11	95.32	1.00	-14.44
17	GO-6 × Kashi Kranti	1.42	-0.67*	0.00	9.65	0.27	0.55	95.38	1.15	-3.05
18	GO-6 × Parbhani Kranti	1.39	0.01	0.01	10.15	1.53	0.04	92.90	0.99	-16.21
19	AOL-16-04 × Arka Anamika	1.50	0.15	0.00	11.61	1.18	0.38	98.93	1.19	6.87
20	AOL-16-04 × Arka Abhay	1.44	0.12	0.01*	10.84	0.87	0.00	95.77	1.23	-16.45
21	AOL-16-04 × Kashi Kranti	1.53	-0.36*	0.00	10.11	0.30	1.07*	96.11	0.91	-13.04
22	AOL-16-04 × Parbhani Kranti	1.55	0.30	0.00	11.51	1.25	0.07	97.60	1.29	113.81**
23	NOL 17-05 × Arka Anamika	1.50	0.28	0.00	10.79	1.37	0.05	93.68	0.85*	-27.44
24	NOL 17-05 × Arka Abhay	1.95	3.95	0.08**	10.20	1.68	0.68	96.54	0.95	-27.06
25	NOL 17-05 × Kashi Kranti	2.11	4.40	0.05**	10.49	0.95	-0.18	96.28	1.17	-5.37
26	NOL 17-05 × Parbhani Kranti	1.36	0.22**	-0.01	9.58	0.79	-0.01	93.37	0.95	21.16
27	NOL 17-06 × Arka Anamika	1.42	-0.21*	0.00	10.26	1.44	0.04	97.48	1.22*	-26.76
28	NOL 17-06 × Arka Abhay	1.39	0.27	0.00	10.46	1.38	-0.16	93.01	1.01	-20.47
29	NOL 17-06 × Kashi Kranti	1.40	-0.26	0.00	10.16	0.98	1.27*	93.53	1.30*	-19.56
30	NOL 17-06 × Parbhani Kranti	1.96	4.20	0.07**	8.78	0.79	0.09	91.70	1.22	26.66
31	NOL 17-09 × Arka Anamika	1.98	3.41	0.03**	11.12	1.61	0.25	96.18	1.02	4.27
32	NOL 17-09 × Arka Abhay	2.24	5.12	0.08**	11.68	1.55	1.53**	86.76	1.25	6.06
33	NOL 17-09 × Kashi Kranti	2.18	4.92*	0.04**	10.36	1.22	-0.29	93.33	1.17	5.58
34	NOL 17-09 × Parbhani Kranti	1.70	2.19	0.03**	10.65	1.46	-0.12	82.85	0.89	-18.55
	Hybrid Mean	1.58			10.35			94.12		
35	Check (OH-102)	1.32	-0.58	0.01	9.01	0.51	0.08	87.73	0.90	83.03*
	General Mean	1.57			10.21			91.88		

For average fruit girth, the parental mean was 1.52 cm and the hybrid mean was 1.58 cm. Of 35 genotypes, 21 genotypes had a non-significant deviation from linear regression and nine genotypes had higher average fruit girth than the population mean; out of which, none was identified as (bi > 1 and significant: zero, bi = 1: zero and bi < 1 and significant: zero) well adapted to various environments, as those which had a statistically minimum deviation from regression coefficient, had lower average fruit girth than the respective mean. Thus, none of the genotypes full filled the required stability parameters.

For average fruit weight, the mean values for parents and hybrids were 9.88 g and 10.35 g, respectively. Out of 35 genotypes, 31 genotypes had a non-significant deviation from linear regression and 15 genotypes had higher average fruit weight than the population mean; out of these genotypes, six genotypes were recognized as (bi > 1 and significant: two, bi = 1 and non-significant: four and bi < 1 and significant: zero) sound adapted to diverse environments. Among the parental genotypes, GAO-5 (Mean = 10.02; bi = 1.53 significant; S2di = -0.32 NS) and NOL 17-05 (Mean = 10.15; bi = 1.87 significant; S^2di = -0.31 NS) exhibited below average stability and specifically adapted to favorable environment. From the hybrids, AOL-16-04 × Arka Anamika (Mean = 11.61; bi = 1.18 non-significant; S^2di = 0.38 NS), AOL-16-04 x Arka Abhay (Mean = 10.84; bi = 0.87 non-significant; S^2di = 0.00 NS), AOL-16-04 × Parbhani Kranti (Mean = 11.51; bi = 1.25 non-significant; S^2di = 0.07 NS) and NOL 17-09 × Arka Anamika (Mean = 11.12; bi = 1.61 non-significant; S^2di = 0.25 NS) had average stability.

For plant height at final harvest, the parental mean and hybrid mean were 86.50 cm and 94.12 cm, respectively. Out of 35 genotypes, 33 genotypes had a non-significant deviation from linear regression and 23 genotypes had higher plant height than the population mean; out of these genotypes, eight genotypes were identified as (bi > 1 and significant: two, bi = 1 and non-significant: five and bi < 1 and significant: one) well adapted to various environments. Among the parental genotypes, AOL-16-04 (Mean = 95.51; bi = 1.01 non-significant; S^2di = 8.37 NS) had average stability whereas, parent GAO-5 showed above average stability (Mean = 86.70; bi = 0.74 significant; S^2di = 5.70 NS) and specifically adapted to poor environment. Among the hybrids, GAO-5 × Arka Abhay (Mean = 98.51; bi = 1.06 non-significant; S^2di = -25.23 NS), AOL-16-04 × Arka Anamika (Mean = 98.93; bi = 1.19 non-significant; S^2di = 6.87 NS), NOL 17-05 × Arka Abhay (Mean = 96.54; bi = 0.95 non-significant; S^2di = -27.06 NS) and NOL 17-09 × Arka Anamika (Mean = 96.18; bi = 1.02 non-significant; S^2di = -4.27 NS) had average stability while, GAO-5 × Kashi Kranti (Mean = 95.06; bi = 1.23 significant; S^2di = -24.82 NS) and NOL 17-06 × Arka Anamika (Mean = 97.48; bi = 1.22 significant; S^2di = -26.76 NS) showed below average stability and specifically adapted to favourable environment.

Table 5: Stability parameters for branches/plant at final harvest, internodes/plant at final harvest and fruits/plant of parents and hybrids in okra.

Sr. No.	Genotypes	Branches/plant at final harvest			Internodes/plant at final harvest			Fruits/plant		
		Mean	b_i	S^2_{di}	Mean	b_i	S^2_{di}	Mean	b_i	S^2_{di}
	PARENTS									
	FEMALES (LINES)									
1	GAO-5	1.05	0.68	0.14**	13.77	0.72	0.18	13.07	0.86	0.78
2	GO-6	0.87	0.40	0.10**	13.97	0.99	-0.04	12.27	0.81	0.30
3	AOL-16-04	2.12	1.72*	0.01	15.30	1.26	0.40	13.70	1.44	2.17*
4	NOL 17-05	0.95	0.55	0.04*	14.32	0.98	0.01	12.72	0.93	0.42
5	NOL 17-06	0.65	0.80	0.22**	13.28	0.87	-0.04	11.62	0.90	0.21
6	NOL 17-09	2.03	2.27	0.46**	12.73	0.85	-0.45	12.05	0.81	0.20
	MALES (TESTERS)									
7	Arka Anamika	1.08	1.31	0.06**	13.30	0.94	-0.35	11.90	0.97	-0.24
8	Arka Abhay	1.03	1.06	-0.01	13.02	0.69	0.34	12.27	1.02	1.45*
9	Kashi Kranti	1.19	1.03	0.02	13.98	0.92	-0.45	12.08	0.73**	-0.59
10	Parbhani Kranti	1.16	0.84	0.07**	13.82	0.77	0.84	12.75	0.79	0.12
	Parental mean	1.21			13.75			12.44		
	HYBRIDS									
11	GAO-5 × Arka Anamika	1.03	1.15	0.06**	15.35	0.67	0.16	13.53	1.01	0.36
12	GAO-5 × Arka Abhay	1.23	0.89	0.08**	14.93	0.92	0.40	13.73	1.12	-0.17
13	GAO-5 × Kashi Kranti	0.89	1.03	0.21**	14.73	0.93	-0.37	13.25	0.98	-0.51
14	GAO-5 × Parbhani Kranti	0.92	1.20	-0.01	14.85	0.85	-0.51	13.57	0.83	1.56*
15	GO-6 × Arka Anamika	1.13	0.69	0.04*	15.20	0.92	-0.65	13.52	1.09	-0.55
16	GO-6 × Arka Abhay	0.92	0.62	0.09**	15.28	0.85	-0.51	13.75	0.79	0.17
17	GO-6 × Kashi Kranti	1.25	0.53*	0.00	15.77	1.11	-0.63	13.45	0.83	-0.29
18	GO-6 × Parbhani Kranti	1.23	0.86	0.04*	15.72	1.11	-0.39	13.53	0.98	-0.53
19	AOL-16-04 × Arka Anamika	1.73	1.28	0.07**	15.95	0.91	-0.13	14.77	1.17	0.89
20	AOL-16-04 × Arka Abhay	1.42	0.73	0.16**	14.93	1.26	-0.31	13.92	1.09	-0.35
521	AOL-16-04 × Kashi Kranti	1.70	0.41	0.04*	15.60	0.95*	-0.66	14.68	0.93	0.11
22	AOL-16-04 × Parbhani Kranti	1.87	0.52	0.03*	15.50	0.94	1.34	14.77	1.10	2.09*
23	NOL 17-05 × Arka Anamika	1.25	0.60	0.00	15.87	1.03	-0.53	13.90	0.93*	-0.61
24	NOL 17-05 × Arka Abhay	0.93	0.53	0.14**	16.20	1.14	-0.57	13.82	1.12	-0.55
25	NOL 17-05 × Kashi Kranti	1.15	1.25	0.06**	15.97	1.30	-0.44	13.62	1.00	-0.43
26	NOL 17-05 × Parbhani Kranti	1.20	1.18	0.04*	15.68	1.16	-0.34	13.93	1.26	0.72
27	NOL 17-06 × Arka Anamika	1.55	1.38	0.36**	15.47	1.23*	-0.58	14.15	1.12*	-0.59
28	NOL 17-06 × Arka Abhay	0.87	0.87	0.00	14.60	1.13	-0.43	13.13	1.00	-0.05
29	NOL 17-06 × Kashi Kranti	1.17	1.20	0.06**	14.23	1.20	0.72	13.52	1.42*	-0.41
30	NOL 17-06 × Parbhani Kranti	0.98	1.05	0.10**	14.42	1.14	-0.57	12.82	1.02	-0.48
31	NOL 17-09 × Arka Anamika	1.83	1.59	0.27**	16.05	0.94	0.50	15.60	1.31	0.00
32	NOL 17-09 × Arka Abhay	1.95	1.77	0.09**	15.17	1.27	0.55	12.97	0.93	-0.46
33	NOL 17-09 × Kashi Kranti	1.43	1.44*	0.00	14.85	1.27**	-0.66	13.58	1.24*	-0.58
34	NOL 17-09 × Parbhani Kranti	1.88	1.71*	0.01	13.83	0.93	-0.30	12.62	0.93	-0.58
	Hybrid Mean	1.31			15.26			13.76		
35	Check (OH-102)	2.1	-0.10*	0.06**	14.15	0.86*	-0.64	13.58	0.54	1.07
	General Mean	1.28			14.81			13.37		

For branches/plants at final harvest, the parental mean and hybrid mean were 1.21 and 1.31, respectively. Out of 35 genotypes, nine genotypes had a non-significant deviation from linear regression, from which three genotypes had a higher number of branches/plants than the population means; these three genotypes were identified as (bi > 1 and significant: three, bi = 1 and non-significant: zero and bi < 1 and significant: zero) well adapted to various environments. Among the parental genotypes, none of the genotypes had average stability. But parent AOL-16-04 showed below average stability (Mean = 2.12; bi = 1.72 significant and S^2di = 0.01 NS) and specifically adapted to a favourable environment. Among the hybrids, NOL 17-09 × Kashi Kranti (Mean = 1.43; bi = 1.44 significant and S^2di = 0.00 NS) and NOL 17-09 x Parbhani Kranti (Mean = 1.88; bi = 1.71 significant and S^2di = 0.01 NS) had below-average stability and specifically adapted to favourable environment.

Table 6: Stability parameters for fruit yield/plant of parents and hybrids in okra.

Sr. No.	Genotypes	Fruit yield/plant		
		Mean	b_i	S^2_{di}
	PARENTS			
	FEMALES (LINES)			
1	GAO-5	162.50	0.86	159.83
2	GO-6	144.40	0.79	466.69**
3	AOL-16-04	157.60	1.28	450.69*
4	NOL 17-05	157.20	1.14	262.02*
5	NOL 17-06	138.80	0.75	-61.00
6	NOL 17-09	144.50	0.83	105.72
	MALES (TESTERS)			
7	Arka Anamika	141.10	0.74	58.57
8	Arka Abhay	137.30	0.70	359.62*
9	Kashi Kranti	134.30	0.61*	-92.48
10	Parbhani Kranti	147.80	0.69	-39.17
	Parental mean	146.55		
	HYBRIDS			
11	GAO-5 × Arka Anamika	167.70	0.95	13.83
12	GAO-5 × Arka Abhay	164.10	0.97	-105.89
13	GAO-5 × Kashi Kranti	146.60	0.93	-101.20
14	GAO-5 × Parbhani Kranti	156.30	0.72	154.98
15	GO-6 × Arka Anamika	154.30	0.77	-41.96
16	GO-6 × Arka Abhay	162.90	1.03	-8.03
17	GO-6 × Kashi Kranti	152.60	0.74	310.60*
18	GO-6 × Parbhani Kranti	163.20	1.18	-45.73
19	AOL-16-04 × Arka Anamika	196.30	1.36	2.31
20	AOL-16-04 × Arka Abhay	174.80	1.13	-108.88
21	AOL-16-04 × Kashi Kranti	171.80	0.91	46.00
22	AOL-16-04 × Parbhani Kranti	193.10	1.16	-2.66
23	NOL 17-05 × Arka Anamika	175.60	1.19*	-111.35
24	NOL 17-05 × Arka Abhay	168.50	1.43	36.44
25	NOL 17-05 × Kashi Kranti	166.40	1.01	-51.49
26	NOL 17-05 × Parbhani Kranti	155.50	0.97	-64.66
27	NOL 17-06 × Arka Anamika	170.00	1.17	17.17
28	NOL 17-06 × Arka Abhay	162.50	1.16	-77.66
29	NOL 17-06 × Kashi Kranti	159.60	1.11	122.18
30	NOL 17-06 × Parbhani Kranti	136.50	0.92	27.10
31	NOL 17-09 × Arka Anamika	201.30	1.68*	62.92
32	NOL 17-09 × Arka Abhay	178.60	1.37	-32.12
33	NOL 17-09 × Kashi Kranti	165.50	1.26*	-110.65
34	NOL 17-09 × Parbhani Kranti	158.30	1.02	-17.99
	Hybrid Mean	166.75		
35	Check (OH-102)	137.80	0.50	27.60
	General Mean	160.81		

For internodes/plants at final harvest, the parental mean and hybrid mean were 13.75 and 15.26, respectively. All the genotypes had a non-significant deviation from linear regression, from which 20 genotypes had higher internodes than the population mean; out of these genotypes, ten were identified as (bi>1 and significant: one, bi=1 and non-significant: eight and bi<1 and significant: one) well adapted to various environments. Among the parents, AOL-16-04 (Mean = 15.30.; bi = 1.26 non-significant; S^2di = -0.40 NS), NOL 17-05 (Mean = 14.32.; bi = 0.98 non-significant; S^2di = -0.01 NS) and Kashi Kranti (Mean = 13.98.; bi = 0.92 non-significant; S^2di = -0.45 NS) had average stability for this trait. Among the hybrids, AOL-16-04 x Arka Anamika (Mean = 15.95; bi = 0.91 non-significant and S^2di = -0.13 NS), NOL 17-05 × Arka Anamika (Mean = 15.87; bi = 1.03 non-significant and S^2di = -0.53 NS), NOL 17-05 × Arka Abhay (Mean = 16.20; bi = 1.14 non-significant and S^2di = -0.57 NS), NOL 17-05 × Kashi Kranti (Mean = 15.97; bi = 1.30 non-significant and S^2di = -0.44 NS) and NOL 17-09 × Arka Anamika (Mean = 16.05; bi = 0.94 non-significant and S^2di = 0.50 NS) had average stability for this trait. The hybrid AOL-16-04 × Kashi Kranti showed above average stability (Mean = 15.60; bi = 0.95 significant; S^2di = -0.66 NS) and specifically adapted to a poor environment. The hybrid NOL 17-06 × Arka Anamika showed below average stability (Mean = 15.47; bi = 1.23 significant; S^2di = -0.58 NS) and specifically adapted to favourable environment.

For fruits/plants, the parental mean and hybrid mean were 12.44 and 13.76, respectively. Out of 35 genotypes, 31 genotypes had a non-significant deviation from linear regression, from which 20 genotypes had a higher number of fruits than the population mean; out of these genotypes, seven were identified as (bi > 1 and significant: one, bi = 1 and non-significant: five and bi < 1 and significant: one) well adapted to various environments. The results revealed that among the parents, GAO-5 (Mean = 13.07; bi = 0.86 non-significant and S^2di = 0.78 NS) had average stability for this trait. Among the hybrids, AOL-16-04 × Arka Anamika (Mean = 14.77; bi = 1.17 non-significant and S^2di = 0.89 NS), AOL-16-04 × Arka Abhay (Mean = 13.92; bi = 1.09 non-significant and S^2di = -0.35 NS) and AOL-16-04 × Kashi Kranti (Mean = 14.68; bi = 0.93 non-significant and S^2di = -0.11 NS) and NOL 17-09 × Arka Anamika (Mean = 15.60; bi = 1.31 non-significant and S^2di = 0.00 NS) had average stability while, NOL 17-05 × Arka Anamika showed above average stability (Mean = 13.90; bi = 0.93 significant and S^2di = -0.61 NS) and specifically adapted to poor environment. The hybrid NOL 17-06 × Arka Anamika showed below-average stability (Mean = 14.15; bi = 1.12 significant and S^2di = -0.59 NS) and specifically adapted to a favourable environment.

For fruit yield/plant, the parental mean and hybrid mean were 146.55 g and 166.75 g, respectively. Out of 35 genotypes, 30 genotypes had a non-significant deviation from linear regression, from which 17 genotypes had higher fruit yield than the population mean; out of these genotypes, eight genotypes were identified as (bi > 1 and significant: two, bi = 1 and non-significant: six and bi < 1 and significant: zero) well adapted to various environments. The results revealed that among the parents, GAO-5 (Mean = 162.50; bi = 0.86 non-significant and S^2di = 159.83 NS) had average stability for this trait. Among the hybrids, AOL-16-04 × Arka Anamika (Mean = 196.30; bi = 1.36 non-significant and S^2di = 2.31 NS), AOL-16-04 × Arka Abhay (Mean = 174.80; bi = 1.13 non-significant and S^2di = -108.88 NS), AOL-16-04 × Kashi Kranti (Mean = 171.80; bi = 0.91 non-significant and S^2di = 46.00 NS), AOL-16-04 × Parbhani Kranti (Mean = 193.10; bi = 1.16 non-significant and S^2di = -2.66 NS) and NOL 17-06 × Arka Anamika (Mean = 170.00; bi = 1.17 non-significant and S^2di = 17.17 NS) had average stability, while NOL 17-05 × Arka Anamika (Mean = 175.60; bi = 1.19 significant and S^2di = -111.35 NS) and NOL 17-09 × Arka Anamika (Mean = 201.30; bi = 1.68 significant and S^2di = 62.92 NS) showed below average stability and specifically adapted to favourable environment.

Among the genotypes studied, parents and hybrids were identified as stable for average, favourable, and poor environments for yield and its component characters are summarized in Table 7.

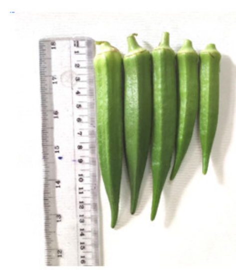
The parent GAO-5 was stable for fruit yield/plant. Further, it was stable for average fruit weight, plant height at final harvest, and fruits/plant. Among the hybrids, AOL-16-04 × Arka Anamika had high mean fruit yield/plant with a regression coefficient near unity and non-significant deviation from regression along with stability for average fruit weight, plant height at final harvest, internodes/plant at final harvest and fruits/plant. Next to it, the cross AOL-16-04 × Arka Abhay showed stability in fruit yield/plant with stability in average fruit weight and fruits/plant, cross AOL-16-04 x Kashi Kranti showed stability in fruit yield/plant with stability in internodes/plant at the final harvest and fruits/plant. Cross AOL-16-04 × Parbhani Kranti in addition to fruit yield/plant also depicted stability for average fruit weight. Cross NOL 17-06 × Arka Anamika in addition to fruit yield/plant, depicted stability for plant height at final harvest, internodes/plant and fruits/plant. On the other hand, NOL 17-05 × Arka Anamika exhibited high fruit yield/plant but its regression coefficient significantly deviates from unity showing below average stability and found suitable for the favourable environment also showed stability for internodes/plants at the final harvest, and fruits/plant. The hybrid NOL 17-09 × Arka Anamika also exhibited below-average stability and was thus found suitable in a favourable environment. However, it exhibited stability for average fruit weight, plant height at final harvest, internodes/plants at final harvest, and fruits/plant.

Table 7: Classification of genotypes based on their well adaptation in better, average and poor environments for yield and its component traits.

Characters	Average stability and wide/ general adaptability	Above average stability and adapted to poor environment	Below average stability and adapted to better environment
Average fruit weight	AOL-16-04 × Arka Anamika AOL-16-04 × Arka Abhay AOL-16-04 × Parbhani Kranti NOL 17-09 × Arka Anamika	-	GAO-5 NOL 17-05
Plant height at final harvest	AOL-16-04 GAO-5 × Arka Abhay AOL-16-04 × Arka Anamika NOL 17-05 × Arka Abhay NOL 17-09 × Arka Anamika	GAO-5	GAO-5 × Kashi Kranti NOL 17-06 × Arka Anamika
Branches/plant at final harvest	-	-	AOL-16-04 NOL 17-09 × Kashi Kranti NOL 17-09 × Parbhani Kranti
Internodes/plant at final harvest	AOL-16-04 NOL 17-05 Kashi Kranti AOL-16-04 × Arka Anamika NOL 17-05 × Arka Anamika NOL 17-05 × Arka Abhay NOL 17-05 × Kashi Kranti NOL 17-09 × Arka Anamika	AOL-16-04 x Kashi Kranti	NOL 17-06 × Arka Anamika
Fruits/plant	GAO-5 AOL-16-04 × Arka Anamika AOL-16-04 × Arka Abhay AOL-16-04 × Kashi Kranti NOL 17-09 × Arka Anamika	NOL 17-05 x Arka Anamika	NOL 17-06 × Arka Anamika
Fruit yield/plant	GAO-5 AOL-16-04 × Arka Anamika AOL-16-04 × Arka Abhay AOL16-04 × Kashi Kranti AOL-16-04 × Parbhani Kranti NOL 17-06 × Arka Anamika	-	NOL 17-05 × Arka Anamika NOL 17-09 × Arka Anamika


GAO-5


AOL-16-04 × Arka Anamika


AOL-16-04 × Arka Abhay


AOL-16-04 × Kashi Kranti


AOL-16-04 × Parbhani Kranti


NOL-17-06 × Arka Anamika


NOL-17-05 × Arka Anamika


NOL-17-09 × Arka Anamika

Fig. 1. Identified stable genotypes.

CONCLUSIONS

Thus, it can be summarized that for overall stable performance in fruit yield of the hybrid, one or more component characters might be responsible. So, by selecting stability in some yield components, the likelihood for the selection of stable hybrids increases. Grafius (1956) suggested that the stability of distinct yield components may be the cause of the stability of fruit yield. The average yield of each genotype rests on a particular set of environmental conditions. To find a stable genotype during selection, it would be beneficial to do real testing under a wide range of environments, including both favourable and unfavourable ones. The phenotypic stability of traits directly associated with fruit yield should get the appropriate amount of attention, particularly, fruit weight, plant height at final harvest, internodes/plant at final harvest and fruits/plant so as to achieve maximum stability for the end product *i.e*., fruit yield in okra. Such results were also reported by Patil *et al*. (2017); More *et al.* (2018); Vekariya *et al.* (2019).

For all the examined characteristics, no genotype was stable. Since the genotype may not concurrently display uniform responsiveness and stability patterns for all of these characteristics, any generalization about the stability of genotypes for all of the traits is therefore too difficult. Nevertheless, given that certain lines greatly outperformed the commercial check "OH-102", when averaged across environments, revealed the likelihood of producing particular lines for particular situations. However, for more reliable recommendations, these lines need to be tested in a manifold location.

FUTURE SCOPE

A multitude of component characters interacts to determine fruit yield, is a complicated and polygenically regulated attribute. Therefore, is need to choose the right yield related components traits for yield, that may aid both with the high and stable yield in a wide range of environments. So, it is important to have a thorough knowledge of the interrelationships between fruit yield and its component traits.

Acknowledgement. The authors acknowledge the support given by the Department of Genetics and Plant Breeding and the Department of Vegetable Science, Navsari Agricultural University, Navsari, Gujarat, India.

Conflict of Interest. None.

REFERENCES

Allard, R. W. and Bradshaw, A. D. (1964). Implications of genotype environmental interactions in applied plant breeding. *Crop Science, 4,* 503-508.

Anonymous (2021). [http://faostat.fao.org/.]

Baker, R. J. H. (1969). Genotype × environment interactions in yield of wheat. *Journal of Plant Science*, *49*, 743-751.

Comstock, R. E. and Moll, R. E. (1963). Genotype-environment interactions. *In*: "Statistical Genetics and Plant Breeding, NAS-NRC Pub., *982*, 164-196.

de Candolle, A. P. (1883). *Origin of Cultivated Plants.* Noble Offer Printing Inc. 1983 New York. pp. 150.

Eberhart, S. A. and Russell, W. A. (1966). Stability parameters for comparing varieties. *Crop Science*, *6*, 26-40.

FAOSTAT (2021). [https://www.fao.org/faostat/en/#data/QCL/visualize]. [Visited on 27 December, 2021]

Grafius, J. E. (1956). Components of yield in oats, a geometrical interpretation. *Journal of Agronomy*, *51*, 515-554.

Kang, M. S. (1998). Using genotype-by-environment interaction for crop cultivar development. *Advance in Agron*omy, *35,* 199–240.

More, S. J., Chaudhari, K. N., Vaidya, G. B. and Chawla, S. L. (2018). Genotype x Environment interaction and stability analysis for earliness, seed yield and fruit yield in okra using the additive main effect and multiplicative interaction (AMMI). *International Journal of Current Microbiology and Applied Science*, *7*(03), 373-383.

Patel, A. A., Patel, A. I., Parekh, V. B., Patel, R. K., Mali, S. C. and Vekariya, R. D. (2020). Estimation of standard heterosis over environments for fruit yield and its attributes in Okra [*Abelmoschus esculentus* (L.) Moench]. *International Journal of Chemical Studies*, *8*(6), 2542-2547.

Patil, S. S., Desai, D. T., Patil, P. P. and Patel, S. R. (2017). Genotype x environment interaction for fruit yield and component characters in okra [*Abelmoschus esculentus* (L.) Moench]. *Electronic Journal Plant Breeding*, *8*(3), 787-791.

Sprague, G. F. (1966). Quantitative genetics in plant improvement. In Plant Breeding. A symposium held at the Iowa State University (Ed. K.J. Frey) pp. 351-354.

Singh B. and Y. K. Shukla (2022). Estimation of Genotype × Environment interaction for Yield and Yield Contributing Characters in Sesame (*Sesamum indicum* L.). *Biological Forum – An International Journal*, *14*(1), 614- 622.

Ummyiah, H.M., Zeenat Fayaz, Baseerat A., Shehnaz M., M. Mudasir Magray and Gazala, N. (2021). Genotype x Environment Interaction and Fruit Yield Stability in Tomato Hybrids under Kashmir Valley conditions using Additive Main Effects and Multiplicative Interaction (AMMI) Model. *Biological Forum – An International Journal*, *13*(3), 249-254.

Varmudy, V. (2001). Marketing of vegetable in India. Daya Publishing House, New Delhi-110 035, pp. 1-15.

Vekariya, R. D., Patel A. I., Modha K. G. and Mali S. C. (2019). G x E interaction and stability analysis in okra [*Abelmoschus esculentus* (L.) Moench]. *International Journal of Chemical Studies*, *7*(4), 3146-3150.

Vekariya, R. D., Patel, A. I., Modha, K. G., Kapadiya, C. V., Mali, S. C. and Patel, A. A. (2020). Estimation of Heterosis, Gene Action and Combining Ability over Environments for Improvement of Fruit Yield and its Related Traits in Okra [*Abelmoschus esculentus* (L.) Moench]. *International Journal of Current Microbiology and Applied Science*, *9*(9), 866-881.

Zeven, A. C. and Zhukovsky, P. M. (1975). Dictionary of cultivated plants and their centres of diversity. Centre for Agricultural publishing and Documentation, Wegeningen, Netherlands. pp. 219.

How to cite this article: A.A. Patel, R.D. Vekariya, A.I. Patel and A.G. Singh (2023). Insights into Phenotypic Stability of Okra [*Abelmoschus esculentus* (L.) Moench] Hybrids Evaluated under Multi Environments. *Biological Forum – An International Journal, 15*(2): 1185-1194.