Plant Archives Vol. 25, Supplement 1, 2025 pp. 1280-1285 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-1.174

ASSESSING YIELD STABILITY AND ASSOCIATED TRAITS IN OKRA (*ABELMOSCHUS ESCULENTUS* L. MOENCH)

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(Date of Receiving : 05-08-2024; Date of Acceptance : 26-10-2024)

ABSTRACT

Fourteen okra genotypes including one check were evaluated under three different environments by changing the fertility conditions at the Experimental Farm, Department of Horticulture, Assam Agricultural University during 2022 to study the genotype-environment interaction. Pooled analysis of variance revealed significant variation among the genotypes and GE interaction studied for all the characters. From the stability analysis, the genotype IC-0620645 was found to have average stability for yield per plant. Hence,the genotype was found most suitable for stable yield performance under a wide range of environments. Environment 2 (N:P:K @ 50:50:50 kg/ha) was found as the favourable environment for the character yield/plant.
***Keywords*:** Okra, Stability, Environments, Genotype, Fertility

Introduction

Okra (*Abelmoschus esculentus* L. Moench is an annual vegetable crop belonging to the family Malvaceae and it is also known as the Queen of Vegetables. It is mainly cultivated for its edible fruits and it is often-cross-pollinated in nature. Okra is propagated by seeds with a duration of three to four months (Rani and Kumar, 2022). It is also an important source of nutrients including vitamins, minerals and iodine which is useful for the treatment of goitre. Okra seeds are said to contain around 14% edible oil and 15 to 26% of protein (Oppong *et al*., 2011). India ranks first in okra production having an area of 509 thousand hectares with an annual production of 6094.9 thousand MT and productivity of 12.0 MT/ha (National Horticultural Board, 2018). In the recent years numerous attempts have been made through various breeding programmes to create cultivars that are environmentally stable and genetically superior in terms of yield.

Yield stability is one of the most important properties of the genotypes to be released as a new variety. However, great fluctuations in the crop yield are observed due to the non-adaptability of the varieties in variable agro-climatic conditions (Prakash *et al*., 2017). Information on the stability of fruit yield and its component traits is crucial in comprehending the mechanisms underlying yield stability since GxE interaction evaluates the changes in how genotype responds to changing environments (Javia, 2014). Therefore, keeping in view all the above points, the present study is designed with the objectives to study the genotype environment interaction of 14 okra genotypes under different fertility conditions for stability analysis.

Materials and Methods

Genetic material

The experimental material for the present investigation comprised of 14 genotypes of okra grown under three different fertility conditions (environments)

maintained at the Experimental farm, Department of Horticulture, Assam Agricultural University, Jorhat. The experiment consisted of genotypes developed at NBPGR, Akola station; IIVR, Varanasi; and AAU, Jorhat. Some commonly used local collections of the state were also added in the experiment. The check genotype used in the experiment was Arka Anamika which was developed at IIHR, Bengaluru.

Field trials

The test entries were evaluated under three different fertility conditions (environments). The environments were created by providing 3 fertilizer doses in the form of NPK @ 40:40:40, 50:50:50 and 60:60:60 kg/ha. Out of these the NPK dose 50:50:50 kg/ha is a recommended one for Assam. The fertilizer and organic manure (FYM @ 25t/ha) were mixed thoroughly and applied in rows one day ahead of sowing. The experiment was laid out in Randomized Block Design (RBD) with two replications. The row to row spacing was 45cm and the plant to plant spacing was 30cm. Individual plot size was 3m x 1.35m. Sowing of the seeds were done on 16th June, 2022. Five sample plants from each entry were taken for recording of observations.

Statistical analysis

The mean values of the genotype in each replication were used for analysis of variance. After testing for homogeneity of the error variances obtained from ANOVA of individual environments using Bartlett's test, a pooled ANOVA of the data across the environment was performed. Pooled ANOVA was performed for the characters across environments, with replication, genotype, and environment as fixed effects (Fisher, 1919). Regression-based stability analysis was performed using the Eberhart and Russell (1966) model for studying genotype- environment interaction. The environment plus GE interaction component was further divided into environment (linear), GE (linear), and pooled deviation from regression in the stability analysis study. The three stability parameters proposed under Eberhart and Russell model (Eberhart and Russell, 1966) such as genotype's mean performance (m), the linear regression coefficient of the genotypic mean on environmental indices (bi), and the mean square due to deviation from regression (S^2di) were used to define stability of genotypes.

Results and Discussion

In pooled analysis (Table 1), the variance due to the genotypes and the GE interaction was significantly high for all the characters. This confirmed the existence of genetic diversity among the genotypes and significantly high GE interaction showed that the genotypes under study behaved differently for almost all the characters under diverse environments. Similar findings were also reported in okra by Makhdoomi *et al*. (2018) and Sreenivas (2015).

Stability analysis

The analyses of variance for stability performed for yield and its contributing characteristics in accordance with Eberhart and Russel (1966) model are presented in Table 2. The pooled analysis of variance showed that genotypes differed significantly for all the characters over the environments except for internode length and fruit diameter. The significant to highly significant mean square values for genotypes indicated that the genotypes interacted considerably with the changing environmental conditions for most of the characters including yield. This was in conformity with Dabhi *et al.* (2010). With the exception for the number of nodes, days to last harvest, number of fruits per plant, fruit length, and fruit diameter, all other characters showed highly significant linear environmental variance which indicated that there were significant differences between the environments and their effects were also predominant on the characters. Ezekiel *et al.* (2011) reported significant linear environmental variance for the characters plant height, days to 50% flowering and yield per plant in okra. The pooled deviations were significant for all the characters except for number of nodes indicating a non-linear response to environments. The non-linear component alone was highly significant for days to last harvest, number of fruits per plant, fruit length and fruit diameter which elucidated substantial differences in stability of performance among the genotypes across the environments and major part of the interaction was absolutely unpredictable. Similar findings were reported by Jindal *et al.* (2008), Sreenivas *et al*. (2015) and Kumar *et al*. (2011) in okra.

Stability parameters

The failure of genotypes to achieve the same relative performance in multiple environments has been termed as genotype x environment interactions (Baker, 1988). Therefore, assessment of GE interactions is crucial for plant breeding since it allows for assessment of stability performance of a genotype under various environmental conditions. Eberhart and Russell (1966) proposed three stability parameters for measuring phenotypic stability. These are the mean performance of the genotypes (m), the linear regression coefficient of the genotypic mean on environmental indices (b_i), and the mean square due to deviation from regression (S^2_{di}). In Eberhart and Russell's model, an ideal variety is one with a high mean performance, unit

regression (b_i = 1), and the least deviation from regression (S^2_{di} = 0). The genotypes were classified as 'below average stable' (BAS) if the regression coefficient was significantly more than unity (b_i>1), and as 'above average stable' (AAS) if the regression coefficient was significantly lower than unity (b_i<1). A regression value greater than unity shows that the variety is sensitive to changes in environmental conditions, and such a variety is predicted to perform better than its inherent potential in high yielding situations, but poor under stress conditions. A regression value smaller than unity for a variety indicates its insensitivity to changes in the environment, making it particularly ideal for stress environments. Stability parameters of the 12 traits in 14 okra genotypes over 3 environments are represented in Table 3. In table 3 (a) stability parameters of the 3 traits related to duration are presented. In table 3 (b) stability parameters of the trait days to last harvest and 2 yield related traits are presented. And table 3 (c) and table 3 (d) presents the stability parameters of the 6 yield related traits in 14 okra genotypes.

Yield of okra differs significantly based on the condition of the environment. Therefore, a variety with a stable yield is preferred to reduce the risk of yield loss in unfavorable environments. The genotype IC-0620645 showed average stability (AS) for yield per plant and number of nodes per plant. Hence this genotype was most suitable for stable yield performance under a wide range of environment. Average stability was shown by the genotypes JOC-1, JOC-2, JOC-4, Arka Anamika, EC-305653 and EC-305727 for different characters such as number of nodes, internode length, days to 50% flowering, days to 50% fruiting, days to 1st harvest and number of flowers per plant. It indicates that these varieties show average response to a wide range of environments for these particular characters.

In the present investigation, below average stability was shown by different genotypes such as EC-305727 for internode length and number of fruits per plant; JOS-30 for number of fruits per plant; and JOS-9 for days to last harvest; JOC-2 for fruit length and fruit diameter; IC-0620645 for days to 1st harvest and fruit length; JOC-3 for internode length and days to last harvest; JOC-4 for internode length; Arka Anamika for plant height and fruit diameter and Kashi Lalima for days to 1st harvest. This indicates that these genotypes are sensitive to changes in environmental conditions for the respective characters. They perform well and give better result than their inherent potentiality in high yielding environment but their performances are poor in unfavorable situations.

Above average stability was shown by the genotypes IC- 27831 for days to 1st harvest and number of fruits per plant; IC-0620645 for number of fruits per plant; JOC-3 for number of nodes and fruit diameter; JOC-4 for plant height; Arka Anamika for days to last harvest and Kashi Lalima for plant height, days to last harvest and number of fruits per plant. These genotypes are insensitive to changes in environmental conditions for the respective characters and are specifically suitable for stress conditions.

Environmental index

Environmental index (I_j) is estimated as the difference between the mean of all the varieties at the respective environment and the grand mean. Environmental index directly reflects the environment by its negative and positive values (Sharifi *et al.,* 2017). The estimates of environmental indices (I_j) for each character under different fertility conditions is presented in Table 4. It was observed that environment 3 (N: P: K @ 60:60:60 kg/ha) was found as the most favorable one for all the characters except for internode length, days to last harvest, number of fruits per plant and yield per plant. Environment 1 (N: P: K @ 40:40:40 kg/ha) had the highest and positive value of environmental indices (I_j) for internode length and days to last harvest and environment 2 (N: P: K @ 50:50:50 kg/ha) had the highest and positive value of environmental indices (I_j) for number of fruits per plant and yield per plant. Therefore, these environments created by providing respective fertility doses appeared to be the most favorable for particular conditions.

Conclusion and Future Line of Work

Pooled analysis of variance for stability revealed that genotypes differed significantly for all the characters over the environments except for internode length and fruit diameter. From the stability analysis, the genotype IC-0620645 was found to have average stability for yield per plant and number of nodes per plant. The variety IC-0620645 showing average stability for yield has great potential to be ideal for different fertility condition if subjected to further trials in different locations of the state.

Table 1: Pooled analysis of variance of the genotypes of okra (*Abelmoschus esculentus* L. Moench) for different characters.

Source	df	Mean squares for											
		Plant height	Number of nodes	Inter-node length	Days to 50% flowering	Days to 50% fruiting	Days to first harvest	Days to last harvest	Number of flowers/ plants	Number of fruits/ plants	Fruit length	Fruit Diameter	Yield / plant
Replication within environment	3	10.79	0.02	0.05	1.96	2.42	0.26	0.334	1.27	2.16	1.96*	0.02*	19.33
Environments	2	296.62*	22.19**	3.12**	13.44	35.12*	3.48*	0.06	24.19*	4.46	0.78	0.02	6,841.75**
Genotypes	13	470.02**	10.18**	2.05**	43.05**	25.58**	20.94**	24.69**	25.19**	24.16**	21.01**	0.08**	7,149.54**
Env x Gen.	26	67.82**	0.09**	1.61**	6.84**	3.41**	1.30**	0.86**	8.69**	5.64**	10.36**	0.06**	1,290.51**
Pooled Error	39	3.86	0.04	0.12	2.36	1.45	0.24	0.26	1.29	1.16	0.35	0.01	34.88
Total	83	104.21	2.18	0.96	10.39	6.69	3.89	4.27	7.90	6.28	6.79	0.03	1706.02
CV %		3.01	1.68	5.60	3.10	2.78	0.95	0.71	5.88	7.12	4.67	4.68	2.90

*Significant at P=0.05; **Significant at P= 0.01

Table 2 : Pooled analysis of variance for stability of 14 okra genotypes over three different environments

Source	d.f.	Mean squares											
		Plant height	Number of Nodes	Inter-node length	Days to 50% flowering	Days to 50% fruiting	Days to first harvest	Days to last harvest	No of flowers per plant	No of fruits per plant	Fruit length	Fruit diameter	Yield /plant
Genotype	13	470.02**	3.86**	2.05	43.06**	25.57**	20.95**	24.68**	25.20*	24.16**	21.01*	0.08	7149.55**
Envt. + GE	28	84.17	1.50	1.71	7.32	5.68	1.46	0.80	9.80	5.56	9.68	0.06	1687.03
Envt. (L)	1	593.18*	4.23	6.23*	26.89*	70.18**	6.99*	0.10	48.37*	8.91	1.56	0.04	13684.10**
GE (L)	13	37.15	1.76	1.91	7.67	3.19	1.48	0.99	6.23	7.23	12.13	0.06	1303.18
Pooled dev.	14	91.47**	1.06	1.21**	5.59*	3.38*	1.04**	0.67**	10.36**	3.77**	7.98**	0.06**	1186.53**
Pooled error	39	3.86	1.16	0.12	2.36	1.45	0.24	0.26	1.29	1.16	0.35	0.01	34.89

*Significant at P=0.05; **Significant at P= 0.01

Table 3 (a): Stability parameters of the 3 traits related to duration in 14 okra genotypes over 3 environments.

Character:	Days to 50% flowering				Days to 50% fruiting				Days to 1st harvest			
Genotypes	Stability Parameters				Stability Parameters				Stability Parameters			
	m	bi	S^2di	Stability	m	bi	S^2di	Stability	m	bi	S^2di	Stability
EC-305727	50.51	2.94	8.15**	-	53.16	2.82**	-0.15	-	53.24	0.74*	0.25	-
JOS-21	51.48	-0.55	-0.99	-	53.81	0.44	-0.58	-	51.83	2.96**	0.70*	-
JOS-30	50.51	1.21	-1.15	-	53.65	0.90	0.59	-	53.86	1.48	0.29	-
JOC-1	50.18	0.40	-1.18	-	53.81	0.68	0.19	-	54.52	0.65	0.28	-
JOS-9	50.99	0.42	6.29*	-	54.14	1.57	2.20*	-	52.18	0.90	-0.12	-
IC- 27831	47.58	1.75	-0.81	AS	50.71	0.41	0.77	AS	49.09	-0.50*	-0.04	AAS
EC-305653	49.37	1.03	5.60*	-	52.02	1.07	0.40	AS	54.94	1.12	-0.12	-
JOC-2	46.76	-1.02	0.37	AS	51.36	0.21	-0.68	AS	51.55	1.20	-0.03	AS
IC-0620645	49.37	5.42**	3.68*	-	52.34	1.90	6.60**	-	50.72	5.00**	0.01	BAS
JOC-3	46.27	-0.04	-0.07	AS	51.04	0.89	-0.16	AS	50.04	-0.67*	3.85**	-
JOC-4	47.74	3.03	-0.28	-	51.85	1.32	-0.62	AS	52.06	-0.12	0.37*	-
IC- 0620644	52.46	-2.08**	0.90	-	55.28	-0.40*	1.90	-	54.58	-1.08**	-0.11	-
Kashi Lalima	54.74	2.46	0.83	-	57.07	1.49	2.83*	-	51.60	0.68	0.36*	-
Arka Anamika ©	44.64	-0.99	1.22	AS	48.91	0.68	0.20	AS	49.85	3.10**	-0.11	BAS

**Significant at 1% level of probability, *Significant at 5% level of probability.

Table 3 (b): Stability parameters of days to last harvest and 2 yield related traits in 14 okra genotypes over 3 environments.

Character:	Days to last harvest				Number of flowers per plant				No of fruits per plant			
Genotypes	Stability Parameters				Stability Parameters				Stability Parameters			
	m	bi	S^2di	Stability	m	bi	S^2di	Stability	m	bi	S^2di	Stability
EC-305727	72.14	3.01	-0.11	-	21.81	1.89	-0.33	AS	16.80	4.07*	1.24	BAS
JOS-21	69.26	6.84	0.04	AS	23.07	0.17	-0.25	AS	18.31	-0.65	0.93	AS
JOS-30	72.99	3.39	-0.13	-	21.02	4.10**	2.03*	-	16.95	6.44**	1.39	BAS
JOC-1	74.08	1.40	-0.08	-	18.17	1.20	26.79**	-	14.09	6.64**	12.14**	-
JOS-9	70.89	16.78*	0.08	BAS	17.69	2.44*	0.04	-	13.79	3.77*	-0.19	-
IC- 27831	69.38	-12.46*	0.43*	-	19.43	-0.75**	2.58*	-	16.20	-4.08**	1.22	AAS
EC-305653	75.39	-4.62	-0.02	-	17.53	1.23	-0.42	-	13.34	1.25	1.79*	-
JOC-2	71.22	7.17	0.48*	-	18.80	1.48	1.42	-	14.69	0.01	-0.58	-
IC-0620645	69.68	12.68	-0.01	AS	20.23	0.38	8.58**	-	16.35	-2.68**	-0.27	AAS
JOC-3	70.88	17.40**	-0.07	BAS	20.54	-0.43*	6.40**	-	16.65	0.01	1.19	AS
JOC-4	74.05	0.67	-0.01	-	18.32	1.87	1.91*	-	14.39	1.26	-0.53	-
IC- 0620644	70.07	1.37	1.82**	-	15.79	1.11	-0.36	-	11.68	1.89	0.46	-
Kashi Lalima	68.92	-18.75**	0.14	AAS	20.86	-0.22*	12.96**	-	16.35	-3.78**	-0.07	AAS
Arka Anamika ©	70.99	-20.89**	0.31	AAS	16.90	-0.47*	2.12*	-	11.83	-0.16	-0.45	-

**Significant at 1% level of probability, *Significant at 5% level of probability.

Table 3 (c): Stability parameters of the 3 yield related traits in 14 okra genotypes over 3 environments.

Character:	Plant height				Number of nodes				Internode length			
Genotypes	Stability Parameters				Stability Parameters				Stability Parameters			
	m	bi	S^2di	Stability	m	bi	S^2di	Stability	m	bi	S^2di	Stability
EC-305727	61.67	0.57	52.24**	-	11.76	3.11	-0.39	-	6.26	-4.53**	-0.01	AAS
JOS-21	51.45	0.97	16.51**	-	10.25	0.32	-0.46	-	5.46	0.65	0.63**	-
JOS-30	67.50	2.19**	39.59**	-	12.21	4.07	-0.21	-	6.11	0.89	0.92**	-
JOC-1	48.33	1.28	-1.62	-	12.81	1.23	-0.26	AS	5.98	-0.18*	0.44**	-
JOS-9	70.00	1.62*	20.37**	-	12.06	3.13	-0.28*	-	5.64	0.36	0.24*	-
IC- 27831	69.33	0.53	29.37**	-	12.96	1.19	1.79	AS	5.99	-0.03*	0.01	-
EC-305653	67.82	2.87**	64.01**	-	11.76	0.97	0.51	-	6.12	1.46	0.63**	-
JOC-2	61.75	0.32*	248.76**	-	12.21	0.97	0.51	AS	5.71	1.78	1.19**	-
IC-0620645	71.67	0.89	9.46*	-	12.81	0.94	-0.58	AS	5.82	0.73	-0.02	-
JOC-3	68.92	1.19	85.55**	-	12.96	-4.04*	-0.44	AAS	7.47	3.55**	0.03	BAS
JOC-4	72.83	-0.76**	-1.47	AAS	12.51	-0.65	-0.09	AS	7.39	4.02**	0.17	BAS
IC- 0620644	52.75	0.38*	50.07**	-	10.70	5.26*	0.29	-	6.14	1.96	0.61**	-
Kashi Lalima	78.25	0.07**	-0.04	AAS	11.91	-0.62	-0.50	-	6.13	3.05**	2.63**	-
Arka Anamika ©	70.58	1.86**	0.47	BAS	11.91	-1.87	-0.56	-	6.39	0.27	0.11	AS

Table 3(d): Stability parameters of the 3 yield related traits in 14 okra genotypes over 3 environments.

Character:	Fruit length				Fruit Diameter				Fruit yield/plant			
Genotypes	Stability Parameters				Stability Parameters				Stability Parameters			
	m	bi	S^2di	Stability	m	bi	S^2di	Stability	m	bi	S^2di	Stability
EC-305727	10.70	-4.13**	7.38**	-	1.517	-0.814	0.01	-	203.47	2.08*	2583.14**	-
JOS-21	10.80	-1.41	1.73**	-	1.58	-2.36*	0.01	-	216.71	-0.93**	686.30**	-
JOS-30	12.22	-12.59**	1.02**	-	1.60	-9.03**	0.03**	-	207.94	0.23**	344.17**	-
JOC-1	10.85	6.49**	6.36**	-	1.63	3.74	0.09**	-	184.09	3.37**	1540.27**	-
JOS-9	12.88	-15.84**	0.49*	-	1.48	-0.89	0.01	-	175.82	2.64**	134.68**	-
IC- 27831	15.27	7.11**	2.17**	-	1.70	-0.49	0.02*	-	249.16	1.52**	84.65*	-
EC-305653	12.78	8.02**	1.21**	-	1.60	2.19	0.08**	-	190.39	0.86	-17.45	-
JOC-2	14.50	18.64**	-0.01	BAS	1.70	6.59**	-0.01	BAS	185.42	1.27	862.75**	-
IC-0620645	12.37	6.17**	-0.17	BAS	1.77	-1.06	-0.01	AS	245.35	1.14	26.18	AS
JOC-3	16.08	-7.88**	1.66**	-	1.82	-3.01**	0.01	AAS	226.81	0.13**	166.81**	-
JOC-4	14.88	-12.14**	13.09**	-	1.72	9.44**	0.05**	-	199.83	-0.26**	1263.46**	-
IC- 0620644	10.42	14.98**	12.62**	-	1.58	3.26	0.08**	-	157.61	1.18	46.42	-
Kashi Lalima	13.33	2.03	2.42**	-	1.88	1.31	0.01	AS	262.32	0.32**	305.26**	-
Arka Anamika ©	11.13	4.55*	3.48**	-	1.60	5.13**	0.01	BAS	142.71	0.43**	34.76	-

Table 4: Estimates of environmental indices (I_j) for each character under different fertility conditions during Kharif season

Characters	E1 (N:P: K – 40:40:40) (kg/ha)	E2 (N:P: K – 50:50:50) (kg/ha)	E3 (N:P: K – 60:60:60) (kg/ha)
Plant height	-3.65	1.05	**2.60**
Number of nodes	-0.11	-0.21	**0.31**
Internode length	**0.19**	-0.38	0.19
Days to 50 % flowering	-0.51	-0.29	**0.79**
Days to 50% fruiting	-1.14	0.05	**1.09**
Days to first harvest	-0.19	-0.22	**0.41**
Days to last harvest	**0.02**	0.02	-0.05
Number of flowers per plant	-1.01	0.18	**0.83**
Number of fruits per plant	-0.44	**0.33**	0.11
Fruit length	-0.19	0.07	**0.12**
Fruit diameter	-0.03	0.01	**0.02**
Yield per plant	-5.39	**17.61**	**-**12.22

Acknowledgement

The authors are thankful to the Department of Plant Breeding & Genetics and Experimental farm, Department of Horticulture, Assam Agricultural University, Jorhat for providing all the financial and infrastructural help for the present study.

Conflict of Interest

The authors state that there are no conflicts of interest related to this article.

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