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Assessment of the Genotype × Environment Interaction in Groundnut (*Arachis hypogaea* L.) Genotypes for Yield and Its Contributing Traits under Different Dates of Sowing

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The forty-five genotypes of groundnut were evaluated at Field Experimentation Centre of the Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Prayagraj (U.P.) during *kharif,* seasons of 2021-22 and 2022-23 in four artificially created environments by four different dates of sowing considered as E-I, E-II, E-III & E-IV. The present experiment was carried

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out in Randomized Block Design with three replications and involved recording observations on 17 yield and its contributing characters. Identifying stable-performing genotypes in the changing environmental scenario is of paramount importance in modern breeding materials. Crop improvement programme mostly depend on the identification of superior and stable genotypes. Mean sum of squares due to environment were found to be substantially distinct for all the traits and the mean sum of square due to genotype were found to be significant for all the characters. The regression coefficients (bi) of the genotypes ranged from -3.40 to 2.52 and the deviation from regression (S^2di) ranged from -1.01 to 1.56. Stability parameters of various traits revealed that GJG-18, RG-574 and RG-559-3 pod yield per plant and RS-1 oil content showed high mean performance and regression coefficient close to unity and non-significant deviation from regression stable under overall environments. Thus indicating the importance of non-linear components in determining interaction of the genotypes with environments in the present study according to the Eberhart and Russell (1966) model.

Keywords: Stability parameters; pod yield; G × E interaction; regression and groundnut.

1. INTRODUCTION

Peanut or groundnut (*Arachis hypogaea* L.) is one of the important oil crops of the *kharif* season. It is widely grown in tropical and subtropical regions of the world [1]. It belongs to the genus *Arachis* and the family Leguminosae. The genus *Arachis* comprises about 80 species which include diploids and tetraploids [2,3,4]. The cultivated type of peanut is a self-pollinated plant having genome size of about 2891 Mbp, which is concentrated on 40 chromosomes exhibiting its tetraploid nature. This genus is divided into nine taxonomic sections based on geographical distribution, cross compatibility and plant morphology [5].

It is an important cash crop grown by millions of small farmers throughout the world, because of its economic and nutritional value [6]. The groundnut kernels consist of about 44-55% oil, 22-32% protein and 8-14% carbohydrates in addition to minerals and vitamins [7]. Its seed is utilized as a source of cooking oil and in confectionary products for consumption by humans [8]. Groundnut oil consists of 32 and 46 percent of polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids (MUFA) respectively [9].

The manifestation of kernel yield and its attributing traits is the result of the genotype (G), the environment (E) in which it is grown, and the interaction between G×E. Genotype by environment (G×E) interaction is significant as it provides information about the impact of test environments on genotype effectiveness and plays a key role in assessing the performance and stability of kernel yield in groundnut genotypes. Enhancing genetic gain in kernel yield performance is possible in part by narrowing the adaptation of genotypes and maximizing yield, particularly when environments are described by G×E interaction [10]. The linear Regression model of Eberhart and Russell [11] is commonly used for the analysis of G×E interaction. In which the b-values (regression) provide information about adaptability and S^2di (deviation from the regression) is utilized as measures of stability of performance.

2. MATERIALS AND METHODS

An investigation was conducted at the Field Experimentation Centre of the Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (U.P). During *kharif,* seasons of 2021-22 and 2022-23 in four artificially created environments by four different dates of sowing (09^{th} June, 2021; 04^{th} July, 2021; 09^{th} July, 2022 & 24^{th} July, 2022) considered as E-I, E-II, E-III & E-IV. The groundnut comprised 45 genotypes, including one check obtained from Rajasthan Agricultural Research Institute, Durgapura, Rajasthan. The list of groundnut genotypes along with their pedigree and origin is presented in Table 1. The investigation field was laid out in Randomized Block Design with three replications. Each entry was accommodated in a single row of 1.5 m length with a spacing of 30 cm between rows and 10 cm between plants within the row. The duration between sowing and pod collection ranged was 94 to 125 days, based on the plant's growth habit. At regular intervals, weeding was carried out and the earthing-up operation was undertaken after applying gypsum. Necessary plant protection measures were adopted except for the spray of fungicides during the crop growth period in all environments. All the recommended package of practices was followed for raising healthy crop. Data were recorded on randomly selected five plants per replication from each genotype of groundnut and average value was used for the statistical analysis for 17 traits *viz.,* days to 50 per cent flowering, days to maturity, plant height (cm), number of branches per plant, number of pegs per plant, number of mature pods per plant, pod yield per plant (g), hundred pod weight (g), kernel yield per plant (g), hundred kernel weight (g), shelling (%), biological yield per plant (g), harvest index (%), SPAD chlorophyll meter reading (SCMR) at 60 DAS, SPAD chlorophyll meter reading (SCMR) at 80 DAS, protein content (%) and oil content (%). Except days to 50 per cent flowering and days to maturity data were recorded on the basis of plot. The data subjected to different statistical analysis *viz.,* analysis of variance (ANOVA); Eberhart and Russell, [11] model was used for assessing the stability performance among the test genotypes involving yield and its contributing characters.

Table 1. List of groundnut genotypes together with their pedigree and origin

S. N.	Genotypes	Pedigree / Selection	Origin
1	SC-28	Pureline selection from Samarala local	PAU, Punjab
2	TMV-10	Selection/ Natural mutant of ‘Argentina’	TNAU
3	GG-16	JSP-14 × JSSP-4 (S-94-15-B-10-1-B-B)	JAU, Junagarh
4	AH-114	G.221 × Go386	CSAUAT, Mainpuri
5	TG-37A	TG-25 × TG-26	BARC, Mumbai
6	TMV-3	Pureline selection from Bassi × Saloum (W.Africa)	TNAU
7	GG-7	S-206 × FESR-8 (1-1-9-B-B)	JAU, Junagarh
8	RG-562	ICG-5013 × RG-141-3	RARI, Durgapura
9	GG-21	Somnath × NCAc 2232	JAU, Junagarh
10	T-28	G.221 × ICG-1697	CSAUAT, Mainpuri
11	PG-1	Selection from Samarala local	PAU, Punjab
12	GG-14	GG-11 × R-33-1	JAU, Junagarh
13	RG-578	ICG-5013 × RG-141	RARI, Durgapura
14	GJG-19	JSSP-12 × LGN-2 (K-99-13-B-1-2-B-B)	JAU, Junagarh
15	GNL	RG-319 × RG-341	RARI, Durgapura
16	RS-1	ICG-5013 × RG-143-2	RARI, Durgapura
17	GJG-18	JSSP-12 × LGN-2 (K-99-13-B-1-1-B-B)	JAU, Junagarh
18	ICGV-00350	ICGV-87290 × ICGV-87846	RARS, Tirupati
19	GJG-17	JSSP-11 × GG-6 (K-99-2-B-1-B-B)	JAU, Junagarh
20	MH-1	AS-414 × AI-703	HAU, Haryana
21	RG-574	ICG 5013-3 × RG-141	RARI, Durgapura
22	AH-334	G.221 × Go343	CSAUAT, Mainpuri
23	RG-382	ICG-5013 × RG-143	RARI, Durgapura
24	RG-575	ICG 5013-2 × RG-141	RARI, Durgapura
25	AK-159	JL-24 × CGC-4018	PDKV, Akola
26	GG-20	27-4-1 × JL-24 (30-2-2-B-B)	JAU, Junagarh
27	S-230	37nc × Arc-1 (301) (Pureline)	UAS, Raichur
28	GG-11	GG-11 × R-33-2	JAU, Junagarh
29	TMV-1	Introduction selection from Ah.288	TNAU
30	RG-561	ICG-5013 × RG-141-2	RARI, Durgapura
31	GG-5	27-5-1 × JL-24	JAU, Junagarh
32	TG-22	TGS-1 × TGE-2	BARC, Mumbai
33	TMV-12	Pureline selection from Uganda	TNAU
34	JL-776	[(ICGV92069 × ICGV93184) SIL4 × ICGV98300]	MPKV, Jalgaon
35	TMV-2	Mass selection from ‘Gudiatham’ bunch AH.32	TNAU
36	GG-6	27-5-1 × JL-24 (30-3-1-B-B)	JAU, Junagarh
37	TMV-4	Pureline from N.Carolina variety	TNAU
38	LGN-1	Selection from LGN-2	MAU, Latur
39	GG-8	27-5-1 × JL-24 (30-3-2-B-B)	JAU, Junagarh
40	RG-141	Kadiri-3 × NCAc 2821	RARI, Durgapura
41	JL-501	Selection from TAG-24	MPKV, Jalgaon
42	RG-510	RG-318 × RG-340	RARI, Durgapura
43	RG-559-3	[(TKG-19A × Kadiri-3) × TKG-19A]	RARI, Durgapura
44	CSMG-2003-19	Amber × ICG-1697	CSAUAT, Mainpuri
45	CSMG-9510	Unnat × ICG-1697	CSAUAT, Mainpuri

3. RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads:

3.1 Analysis of Variance for Stability

The pooled analysis of variance (Eberhart and Russell, 1966) among 45 groundnut genotypes are given in Table 2. Joint regression with regard to the mean performance of a genotype on an environmental index (bi) is the widespread approach in which deviation from regression (S^2di) is used as a measure of stability. Mean sum of squares due to environment were found to be substantially distinct for all the traits and the mean sum of square due to genotype were found to be significant for all the characters. Genotype x environment interaction was found to be significant for days to 50 per cent flowering, plant height, number of branches per plant, number of mature pods per plant, hundred pod weight, shelling, SPAD chlorophyll meter reading (SCMR) at 60 DAS, SPAD chlorophyll meter reading (SCMR) at 80 DAS and protein content. Mean sum of squares due to E + (G×E) were found to be significant for all characters where mean sum of squares due to environment (linear) was significant for days to 50 per cent flowering, plant height, number of branches per plant, number of mature pods per plant, hundred pod weight, hundred kernel weight, shelling, biological yield per plant, harvest Index, SPAD chlorophyll meter reading (SCMR) at 60 DAS, SPAD chlorophyll meter reading (SCMR) at 80 DAS and protein content. Similar results reported by Ghada and Hoda [12], Chavan et al. [13] and Venkateswarlu et al*.* [14].

Stability analysis assist with characterizing the performance of genotypes in various environments and help plant breeding in selecting suitable genotypes while instability is the result of cultivars' response in a different environment which usually shows a high interaction between genetic and environmental factors. As per Eberhart and Russell [11], three parameters mean (µ), regression coefficient (bi) and deviation from regression (S^2di) are indicative of stability of genotypes. Genotypes with high mean (µ) performance, a regression coefficient of unity (bi=1), minimum deviation from regression (S^2di=0) exhibit better general adaptability across environments and are considered stable.

3.2 Stability Parameters for Pod Yield

Genotypes with high mean (µ) performance, a regression coefficient of unity (bi=1), minimum deviation from regression (S^2di=0) exhibit better general adaptability across environments and are considered stable. Stability parameter of pod yield trait depicted in Table 3 and various yield and attributing traits are detailed as under.

The groundnut genotypes exhibited non-significant deviation from regression (S^2di) and regression coefficient value less than unity (bi<1) along with mean value (µ) higher than the overall genotypes mean like SC-28, TMV-10, GG-16, TG-37A, TMV-3, GG-21, RG-578, GNL, RS-1, ICGV-00350, MH-1, AH-334, AK-159, GG-20, S-230, JL-776, TMV-2, GG-8, RG-141 and RG-510 that indicating their stability under unfavorable environments. Some groundnut genotypes AH-114, GG-7, RG-562, T-28, PG-1, GG-14, GJG-19, GJG-17, RG-382, RG-575, GG-11, TMV-1, RG-561, GG-5, TG-22, TMV-12, GG-6, TMV-4, LGN-1, JL-501, CSMG-2003-19, CSMG-9510 exhibited non-significant deviation from regression (S^2di) and regression coefficient value more than unity (bi >1) along with mean value (µ) higher than the overall genotypes mean indicating their stability under favorable environments. Three genotypes GJG-18, RG-574 and RG-559-3 exhibited non-significant deviation from regression (S^2di) and regression coefficient value equal the unity (bi ≈ 1) along with mean value (µ) higher than the overall genotypes mean indicating their stability under overall environments.

E + (G×E) were observed to be significant for all characters (expect days to maturity number of pod per plant, pod yield per plant kernel yield per plant, harvest index and oil content) where mean sum of squares due to environment (linear) was significant for all the characters. Pooled deviation was significant for days to maturity, SPAD at 60, SPAD at 80, protein content and oil content there by indicating that genotype differed significantly for these characters. Similar finding reported by Patil et al. [15], Minde et al. [16], Priyanka Kumari et al. [17], Kamble et al. [18] and Coulibaly et al. [19].

Crop improvement program mostly depend on the identification of superior and stable genotypes. Superior groundnut genotype is one that exhibits high yield potential under favorable environmental conditions, while a stable genotype is one that demonstrates consistent

Table 2. Pooled analysis of variance (Eberhart and Russell, 1966) for 45 groundnut genotypes for stability

S.V.	df	DFF	DM	PH	NBP	NPP	PPP	PYP	HWT	KYP	HKW	SH	BYP	HI	SPAD SIXTY	SPAD EIGHTY	PC	OC
Rep within Env.	8	1.06	0.79	2.96	0.57	1.82	1.37	0.40	15.83**	2.10	1.38	1.74	4.76**	3.67	5.62*	0.92	0.03	2.39
Varieties	44	20.17**	567.10**	99.07**	17.65**	176.29**	86.27**	18.50**	1643.69**	9.71**	90.99**	11.18**	90.41**	7.39**	10.81**	7.12**	0.67**	3.70**
Env + (Var.* Env.)	135	0.58**	1.83	0.51**	0.27**	0.33	0.68**	0.54	1.33**	0.46	1.20**	1.25**	2.14*	1.03	12.03**	8.23**	0.48**	0.91
Environments	3	17.59**	31.41**	3.83**	6.15**	2.59**	2.68**	2.07*	35.59**	2.05**	31.95**	1.90*	5.15*	4.78*	396.89**	262.43**	10.17**	4.12*
Var.* Env.	132	0.19**	1.16	0.44*	0.14**	0.28	0.64**	0.50	0.56**	0.42	0.51	1.23**	2.076	1.01	3.28*	2.45**	0.26**	0.88
Environments (Lin.)	1	52.79**	94.23**	11.51**	18.46**	7.79**	8.04**	6.22**	106.77**	6.15**	95.87**	5.69**	15.45**	5.36*	1190.67**	787.30**	30.52**	6.36*
Var.* Env. (Lin.)	44	0.38**	0.38	0.75**	0.30**	0.35	1.13**	0.14	1.06**	0.28	0.71*	2.42**	3.10**	1.37*	5.11**	4.84**	0.50**	0.75
Pooled Deviation	90	0.10	1.52**	0.28	0.06	0.24	0.38	0.67	0.30	0.48	0.40	0.62	1.59	0.81	2.32**	1.23*	0.14**	0.93**
Pooled Error	352	0.17	0.49	0.85	0.23	0.77	0.81	0.98	2.23	0.69	1.06	1.08	1.21	0.94	0.75	0.89	0.08	0.53
Total	179	5.39	140.78	24.74	4.54	43.59	21.72	4.95	405.04	2.73	23.27	3.69	23.84	2.59	11.73	7.97	0.53	1.59

DFF-days to 50 per cent flowering, DM-days to maturity, PH-plant height, NBP-number of branches per plant, NPP-number of pegs per plant, PPP-number of mature pods per plant, PYP-pod yield per plant, HWT-hundred pod weight, KYP-kernel yield per plant, HKW-hundred kernel weight, SH-shelling, BYP-biological yield per plant, HI-harvest Index, SPAD SIXTY-SPAD chlorophyll meter reading (SCMR) at 60 DAS, SPAD EIGHTY-SPAD chlorophyll meter reading (SCMR) at 80 DAS, PC-protein content and OC-oil content

Table 3. Estimation of stability parameters for pod yield per plant (g) in 45 groundnut genotypes

Sr. No.	Genotypes	PYP					PYP		
		Mean	Bi	S²Di	Sr. No.	Genotypes	Mean	Bi	S²Di
1	SC-28	36.06	-3.40	-0.81	**24**	RG-575	31.00	1.27	-0.57
2	TMV-10	31.15	-0.32	1.33	**25**	AK-159	37.00	0.37	-0.51
3	GG-16	28.75	0.31	-0.72	**26**	GG-20	33.50	0.68	-0.81
4	AH-114	30.16	1.68	-0.81	**27**	S-230	32.38	0.89	-0.76
5	TG-37A	35.24	0.56	-0.73	**28**	GG-11	34.42	2.43	-0.74
6	TMV-3	29.77	0.38	0.81	**29**	TMV-1	32.30	1.40**	-1.01
7	GG-7	29.22	1.39	-0.78	**30**	RG-561	34.25	1.13	-0.97
8	RG-562	31.85	1.56	-0.68	**31**	GG-5	32.88	1.42	-0.71
9	GG-21	31.12	0.95	-0.91	**32**	TG-22	35.05	1.94	-0.20
10	T-28	32.07	1.18	1.56	**33**	TMV-12	36.37	2.27	-0.94
11	PG-1	35.68	2.06	1.45	**34**	JL-776	34.24	0.77	0.33
12	GG-14	36.02	2.26	-0.43	**35**	TMV-2	32.88	0.07	-0.91
13	RG-578	33.97	0.59	-0.07	**36**	GG-6	33.32	1.32	-0.80
14	GJG-19	36.28	1.62	0.99	**37**	TMV-4	33.32	1.52	0.31
15	GNL	32.50	0.71	-0.78	**38**	LGN-1	29.48	1.36	0.65
16	RS-1	35.68	0.94	-0.35	**39**	GG-8	34.47	0.37	-0.93
17	GJG-18	33.72	1.09	-0.59	**40**	RG-141	30.03	0.91	-0.62
18	ICGV-00350	33.58	0.59	-0.61	**41**	JL-501	31.37	2.52	-0.94

Sr. No.	Genotypes	PYP						PYP	
		Mean	Bi	S^2Di	Sr. No.	Genotypes	Mean	Bi	S^2Di
19	GJG-17	35.42	1.30	1.52	**42**	RG-510	33.82	0.94	-1.01
20	MH-1	31.17	0.01	0.34	**43**	RG-559-3	34.12	1.03	-0.74
21	RG-574	33.53	1.07	-1.00	**44**	CSMG-2003-19	35.78	1.90	-1.00
22	AH-334	30.70	-1.49	-0.21	**45**	CSMG-9510	34.27	1.92	0.04
23	RG-382	32.75	1.53	-0.89		Mean	33.17		

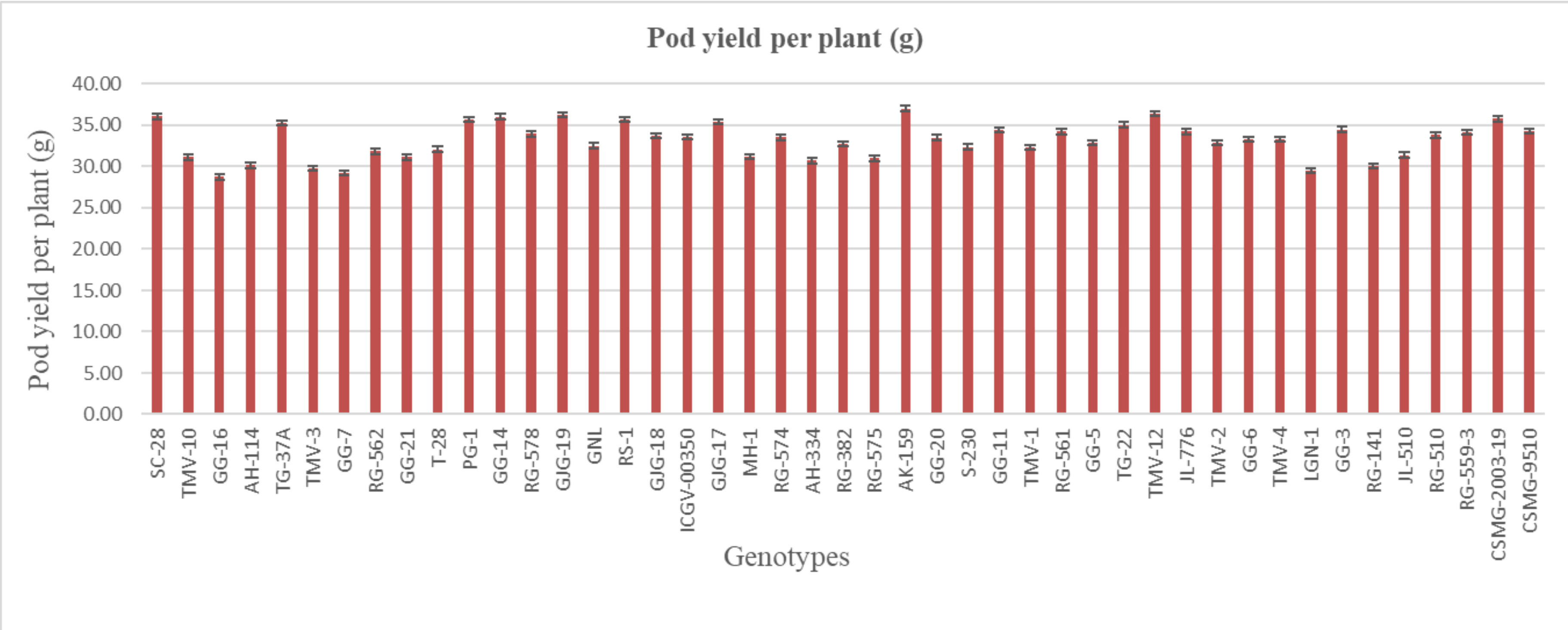

Fig. 1. Mean performance of 45 groundnut genotypes for pod yield per plant (g) pooled over four environments

Table 4. Mean performance of 45 groundnut genotypes for pod yield per plant (g) over four environment-wise and pooled over environments

Sr. No.	Genotypes	E-1	E-II	E-III	E-IV	Pooled	Sr. No.	Genotypes	E-1	E-II	E-III	E-IV	Pooled
1	SC-28	36.47	35.77	35.07	36.93	36.06	**26**	GG-20	34.00	33.07	33.60	33.33	33.50
2	TMV-10	29.63	32.70	31.20	31.07	31.15	**27**	S-230	31.90	32.87	32.67	32.10	32.38
3	GG-16	28.23	29.30	28.87	28.60	28.75	**28**	GG-11	35.00	33.83	35.00	33.83	34.42
4	AH-114	29.73	30.53	30.67	29.70	30.16	**29**	TMV-1	32.33	32.27	32.67	31.93	32.30
5	TG-37A	34.70	35.73	35.47	35.07	35.24	**30**	RG-561	34.07	34.43	34.57	33.93	34.25
6	TMV-3	28.43	31.10	30.00	29.53	29.77	**31**	GG-5	33.47	32.30	33.20	32.57	32.88
7	GG-7	29.73	28.70	29.53	28.90	29.22	**32**	TG-22	36.00	34.10	35.47	34.63	35.05
8	RG-562	32.47	31.23	32.20	31.50	31.85	**33**	TMV-12	36.70	36.03	36.93	35.80	36.37
9	GG-21	31.47	30.77	31.33	30.90	31.12	**34**	JL-776	33.07	35.33	34.60	33.97	34.24
10	T-28	30.50	33.63	32.53	31.60	32.07	**35**	TMV-2	32.57	33.20	32.93	32.83	32.88
11	PG-1	37.30	34.07	36.07	35.30	35.68	**36**	GG-6	33.83	32.83	33.60	33.00	33.32
12	GG-14	36.83	35.20	36.53	35.50	36.02	**37**	TMV-4	34.50	32.13	33.60	33.03	33.32
13	RG-578	33.03	34.93	34.20	33.70	33.97	**38**	LGN-1	28.23	30.73	29.97	29.00	29.48
14	GJG-19	37.73	34.83	36.57	36.00	36.28	**39**	GG-3	34.77	34.17	34.53	34.40	34.47
15	GNL	32.03	32.97	32.73	32.27	32.50	**40**	RG-141	29.43	30.63	30.33	29.73	30.03
16	RS-1	36.50	34.83	35.87	35.53	35.68	**41**	JL-510	31.70	31.03	32.00	30.73	31.37
17	GJG-18	33.10	34.33	34.07	33.37	33.72	**42**	RG-510	33.80	33.83	34.07	33.57	33.82
18	ICGV-00350	32.97	34.20	33.80	33.37	33.58	**43**	RG-559-3	34.67	33.57	34.33	33.90	34.12
19	GJG-17	37.03	33.80	35.60	35.23	35.42	**44**	CSMG-2003-19	35.97	35.60	36.27	35.30	35.78
20	MH-1	30.10	32.40	31.20	30.97	31.17	**45**	CSMG-9510	35.27	33.13	34.73	33.93	34.27
21	RG-574	33.70	33.37	33.80	33.27	33.53		Mean	33.19	33.14	33.43	32.91	33.17
22	AH-334	29.77	31.63	30.40	31.00	30.70		C.V.	4.45	4.72	5.11	6.26	4.82
23	RG-382	33.03	32.30	33.20	32.47	32.75		C.D. 5%	2.40	2.54	2.77	3.34	1.28
24	RG-575	31.70	30.30	31.27	30.73	31.00		Range Lowest	28.23	28.70	28.87	28.60	28.75
25	AK-159	36.30	37.70	37.17	36.83	37.00		Range Highest	37.73	37.70	37.17	36.93	37.00

performance with low interaction. Stability parameters of various traits revealed that GJG-18, RG-574 and RG-559-3 pod yield per plant showed high mean performance and regression coefficient close to unity and non-significant deviation from regression stable under overall environments. Similarly, TMV-12 and CSMG-9510 are found to be most stable for number of branches per plant overall environments. The single genotypes T-28 is found to be most stable for number of mature pods per plant and GJG-17 hundred pod weight overall environments. Hundred kernel weight exhibited stable overall environments some genotypes like TMV-1, CSMG-2003-19 and CSMG-9510.

3.3 Mean Performance for Pod Yield of Test Entries Over Environments

The mean performance of 45 groundnut genotypes analyzed four environments wise as well as pooled over environment are presented in Table 4 respectively and discussed environment wise here under.

The pod yield per plant ranged from 28.23 (GG-16 and LGN-1) to 37.73 (GJG-19) in EI, 28.70 (GG-7) to 37.70 (AK-159) in EII, 28.87 (GG-16) to 37.17 (AK-159) in EIII, 28.60 (GG-16) to 36.93 (SC-28 and AK-159) in EIV and 28.75 (GG-16) to 37.00 (AK-159) in pooled with a 33.19, 33.14, 33.43, 32.91 and 33.17 mean respectively. The genotypes AK-159, TMV-12 and GJG-19 were found to be promising for yield and yield contributing traits under different sowing conditions.

4. CONCLUSIONS

Stability parameters of various traits revealed that GJG-18, RG-574 and RG-559-3 pod yield per plant and RS-1 oil content showed high mean performance and regression coefficient close to unity and non-significant deviation from regression stable under overall environments. The studied genotypes showed differential stability performance for all the characters. None of the genotype was found stable for all the characters under study. Hence, considering mean yield performance, the genotypes AK-159, TMV-12 and GJG-19 were found to be promising for yield and yield contributing traits under different sowing conditions. Thus, three genotypes *viz.* GJG-18, RG-574 and RG-559-3 could be used as parents in hybridization programme for better pod yield and further breeding improvement programme.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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