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Research Article

Genotype x environment interaction studies in rainfed groundnut (*Arachis hypogaea* L.)

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Abstract
A field experiment with 30 rainfed groundnut genotypes was undertaken in randomized complete block design with two replications to study the stability and performance for yield, physiological and quality traits across three sowing dates (environments) during the *kharif* groundnut growing seasons in 2015. Eberhart and Russell's model was used for estimating the stability parameters. The results revealed significant genotype × envirnoment interaction for the traits studied. Partitioning of the environment + (genotype × environment) component into environment (linear) revealed the significance of environment (linear) component for all the traits studied. Further, normal *kharif* season was observed to be congenial for pod yield per plant, sound mature kernel per cent, kernel yield per plant, 100 kernel weight, SCMR, SLA, haulm yield per plant, oil and protein content, while early *kharif* was noticed to be favourable for days to 50 per cent flowering, pods per plant and free proline. Results on stability parameters revealed the potential of K1717 and K1802 genotypes for pod yield per plant; K1899 and K1884 for kernel yield per plant; K1809 and Anantha for oil content for cultivation across the groundnut growing *kharif* seasons studied. The genotype, K1717, however, had recorded high kernel yield per plant, in addition to regression coefficient greater than unity and non-significant deviation from regression, indicating its suitability for cultivation during normal *kharif* season.

Key words
Genotype × environment interaction, Groundnut, physiological, quality, stability, yield

Introduction
Groundnut (*Arachis hypogaea* L.) is an important oilseed crop with oil content around 40-50 per cent. It is popularly known as the "King" of oilseeds or "Wonder nut" or "Poor man's cashew nut". (Thamaraikannan *et al*., 2009) The crop is also an important source of food, feed, nutrition and fodder. In Andhra Pradesh, groundnut is grown in an area of 13.86 lakh ha. with a total production of 12.34 lakh tonnes and productivity of 890 kg/ha (DAC, 2014). The crop is mostly cultivated under rainfed conditions, during *kharif* season. Sowing time, determining crop productivity is an important factor during the season (Banik *et al*., 2009). However, vagaries of monsoon result in varying sowing dates of the crop ranging from early to normal and late sowings. Performance of the crop varieties also varies widely with change in the sowing dates due to existence of genotype × environment (G × E) interaction (Padma and Reddy, 1990). In this context, stability analysis, useful for identification of adaptable genotypes and prediction of performance over changing environments was undertaken in the present investigation for assessing the potential of promising rainfed groundnut genotypes across different *kharif* growing seasons of the crop.

Materials and methods
Experimental material for the present investigation comprised of 30 rainfed groundnut genotypes developed at Agricultural Research Station, Kadiri of Acharya N.G. Ranga Agricultural University. These genotypes were sown on 1st July for early *kharif*, 16th July for normal *kharif* and 6th August for late *kharif* crop. Each genotype was sown in continuous two row plots of 5m row length at a spacing of 30cm between rows and 10cm between plants within the row in a Randomized Complete Block Design with two replications for each date of sowing at Agricultural Research Station, Kadiri during *kharif* 2015. All recommended practices were followed to raise a healthy crop. Observations were recorded on yield, physiological and quality traits, namely, days to 50 per cent flowering, pods per plant, pod yield per plant, sound mature kernel per cemt, kernel yield per plant, 100 kernel weight, SCMR, SLA, oil content, protein and free proline content. The observations were recorded from five randomly selected plants for each genotype, in each replication, while observations on days to 50 per cent flowering, oil content, protein and free proline content were recorded on plot basis. The pooled data across sowing dates was subjected to analysis of variance and the traits showing significant genotype × environment interaction were subjected to stability analysis utilizing Eberhart and Russell model detailed by Singh and Chaudhary (1985) for

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estimating the stability parameters, namely, mean, regression co-efficient (b_i) and mean square deviation (S^2d_i) for each genotype. Significance of the stability parameters were tested by Student't' test.

Results and discussion

Analysis of variance (Table 1) revealed significant mean squares to genotypes and environments for kernel yield, yield components, physiological and quality traits studied in the present investigation, indicating the existence of significant variation among the genotypes studied in addition to considerable environmental variance. Highly significant genotype × environment interaction was also observed for all the traits, indicating a variable response of the genotypes to the different sowing dates studied. The existence of significant genotype × environment interactions for yield, yield components, physiological and quality traits in groundnut crop were also reported earlier by Patil *et al*. (2014) for days to 50 per cent flowering, pods per plant, pod yield per plant, sound mature kernel per cent, 100 kernel weight, kernel yield per plant, haulm yield per plant, oil and protein content; and Teja (2012) for SCMR and SLA.

The results on stability ANOVA for yield, physiological and quality traits also revealed significant genotype × environment interaction. Similar results were reported earlier by Bentur *et al*. (2004). The environment + (genotypes × environment) interaction was also observed to be significant for all traits studied indicating considerable interaction of genotypes with environments and also the distinct nature of environment and genotype × environment interactions in phenotypic expression. Similar results were reported earlier by Kandaswamy *et al*. (1985). Further, partitioning of the environment + (genotype × environment) component into environment (linear) revealed the significance of environment (linear) component for all the traits, indicating that macro-seasonal differences were present under all the three seasons studied and forecast over seasons was possiable. The higher magnitude of mean sum of squares for environment (linear), compared to genotype × environment (linear) indicated that linear response of environment accounted for major part of the total variation for all the traits studied and might be responsible for high adaptation of the genotypes in relation to yield and other traits. Similar findings were reported earlier by Pradhan *et al*. (2010). Further, the mean squares due to genotype × environment (linear) were also significant for days to 50 per cent flowering, sound mature kernel per cent, SLA, haulm yield per plant, protein and free proline content. Similar significant genotype × environment (linear) mean squares for various traits in groundnut were also reported earlier by Chuni Lal *et al*. (2006). However, the mean squares for pooled deviation (non-linear) were also observed to be significant for pods per plant, pod yield per plant, kernel yield per plant, SCMR and haulm yield per plant in the present study indicating that both linear and non-linear components might be contributing to the genotype × environment interaction observed for these traits. The findings are in conformity with earlier reports of Patil *et al*. (2014).

A perusal of the results on environmental indices for yield, physiological and quality traits (Table 2) also revealed variable response of the environments to the different traits studied. De *et al*. (1992) reported that positive and negative values of environmental index indicated the favourable and unfavourable situations, respectively for each character. In the present investigation, the range of environmental index values for different traits studied indicated that the selected environments were quite varied and contrasting with regards to their response for the traits. Similar variable congeniality of different seasons for yield and different yield contributing characters in groundnut was reported earlier by Patil *et al*. (2014). In the present investigation, normal *kharif* was observed to be congenial for pod yield per plant, sound mature kernel per cent, kernel yield per plant,100 kernel weight, SCMR, SLA, haulm yield per plant, oil and protein content, while early *kharif* was noticed to be favourable for days to 50 per cent flowering, pods per plant and free proline.

The number of stable genotypes identified for various traits studied along with the number of stable genotypes with high or desirable mean and their categorization as widely adaptable or suitable for only favourable or poor environments, based on the regression coefficient, b_i value, is presented in Table 3. The results revealed maximum number of stable genotypes (30) for sound mature kernel per cent, oil content, protein and free proline content and minimum for pod yield per plant (17). Further, genotypes with value greater than the general mean and non-significant deviation from regression were higher for sound mature kernel per cent (16) and minimum for pod yield per plant (9). The study also revealed greater number of genotypes with wider adaptability across environments for various traits studied, compared to genotypes adapted to specific environment (poor / favourable). Nine genotypes (K1725, K1719, K1848, K1877, K1884, K1802, K1809, K1717 and K1718) were noticed to possess high pod yield per plant in addition to wide adaptability across the environments studied. Similarly, 10 genotypes (K1725, K1719, K1848, K1878, K1847, K1886, K1877, K1899, K1884 and K1813) were noticed to possess high kernel yield per plant in addition to wide adaptability across the environments studied.

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For oil content, 14 genotypes (K1886, K2047, K1800, K1805, K1809, K1811, K1812, K1813, K1814, K1815, Dharani, Kadiri-9, Kadiri-Harithandhra and Anantha) had recorded high oil content and wide adaptability across the *kharif* seasons studied.

In conclusion, K1717 and K1802 genotypes for pod yield per plant; K1899 and K1884 for kernel yield per plant; and K1809 and Anantha for oil content were identified in the present study for cultivation across the groundnut growing *kharif* seasons studied (Table 4). The genotype, K1717, however, had recorded high kernel yield per plant, in addition to $b_i>1$ and $S^2d_i=0$, indicating its suitability for cultivation in normal *kharif* season.

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Table 1. Mean squares for yield, physiological and quality characters over environments

Source of variation	Degrees of freedom	Mean sum of squares											
		Days to 50% flowering	Pods per plant	Pod yield per plant	Sound mature kernel per cent	Kernel yield per plant	100 kernel weight	SPAD chlorophyll meter reading (SCMR)	Specific leaf area (SLA)	Haulm yield per plant	Oil content	Protein content	Free proline content
Genotypes	29	2.00**	11.24**	4.33**	15.65**	2.13**	33.31**	16.32**	608.57**	12.32**	5.55**	2.88**	418866.06**
Environment + (Genotype × Environment)	60	0.68**	8.19**	12.72**	68.09**	7.84**	7.25**	25.70**	15.31**	3.85**	0.02**	0.03**	1516.98**
Environment	2	14.05**	171.39**	305.15**	1963.64**	211.41**	172.97**	674.11**	261.93**	70.85**	0.42**	0.53**	2350.20**
Genotype × Environment	58	0.22**	2.56**	2.64**	2.73**	0.82**	3.54**	3.34**	6.81**	1.53**	0.10**	0.06***	1488.24**
Environment (Linear)	2	28.11**	342.78**	610.30**	3927.27**	422.82**	345.95**	1348.21**	523.86**	141.70**	0.84**	1.05**	4700.39**
Genotype × Environment (Linear)	29	0.31**	2.95	1.45	4.50**	0.72	1.77	1.35	11.71**	1.99*	0.00	0.01**	2410.36**
Pooled Deviation	30	0.13	2.10**	3.71**	0.93	0.88**	1.26	5.16**	1.84	1.04**	0.01	0.00	547.25
Pooled Error	87	0.13	0.88	0.66	2.10	0.21	1.22	0.92	4.64	0.39	0.02	0.02	1557.82
Total	89	1.11	9.18	9.99	51.01	5.98	15.74	22.64	208.62	6.61	1.82	0.96	137507.13

*, ** Significant at 5 and 1 per cent levels, respectively

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Table 2. Estimation of seasonal indices for yield, physiological and quality traits in groundnut

Character	**Early *kharif***	**Normal *kharif***	**Late *kharif***
Days to 50% flowering	-0.706	0.044	0.661
Pods per plant	2.236	0.284	-2.519
Pod yield per plant	1.501	2.162	-3.663
Sound mature kernel	4.461	4.878	-9.339
Kernel yield per plant	1.197	1.845	-3.042
100 kernel weight	0.798	1.901	-2.699
SPAD chlorophyll meter reading (SCMR)	-5.358	3.649	1.709
Specific leaf area (SLA)	1.063	-3.339	2.276
Haulm yield per plant	0.664	1.093	-1.757
Oil content	-0.083	0.136	-0.053
Protein content	-0.064	0.152	-0.088
Free proline content	9.519	-1.537	-7.982

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Table 3. Distribution of stable genotypes ($S^2\overline{d_i}$=0) with high mean on the basis of regression coefficient (b_i)

Parameter	Days to 50% flowering	Pods per plant	Pod yield per plant	Sound mature kernel per cent	Kernel yield per plant	100 kernel weight	SPAD chlorophyll meter reading (SCMR)	Specific leaf area (SLA)	Haulm yield per plant	Oil content	Protein content	Free proline content
Stable genotypes identified ($\overline{S^2_{di}}$=0)	29	26	17	30	21	28	18	30	26	30	30	30
Genotypes with high mean and stability	13	12	9	16	11	12	11	11	9	14	14	14
Genotypes with high mean, stability and wide adaptability (b_i=1)	10	12	9	12	10	8	11	5	7	14	13	9
Genotypes with high mean, stability and suitable for favourable environment (b_i>1)	2	_	_	4	1	4	_	4	2	_	_	5
Genotypes with high mean, stability and suitable for poor environment (b_i<1)	1	_	_	_	_	_	_	2	_	_	1	_

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Table 4. Details of promising and stable groundnut genotypes identified for cultivation across seasons

	$\bar{x}$	b_i	$\overline{S^2d_i}$	Other stable traits observed for the genotypes
Pod yield per plant				
K1717	14.33	1.602	-0.200	Days to 50 per cent flowering, sound mature kernel per cent, kernel yield per plant, 100 kernel weight, SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA), haulm yield per plant, oil content, Protein content and free proline content.
K1802	14.12	1.309	1.441	Days to 50 per cent flowering, pods per plant, sound mature kernel per cent, kernel yield per plant, 100 kernel weight, specific leaf area (SLA), haulm yield per plant, oil content, Protein content and free proline content.
Kernel yield per plant				
K1899	9.425	1.217	0.474	Days to 50 per cent flowering, pods per plant, sound mature kernel per cent, 100 kernel weight, SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA), haulm yield per plant, oil content, Protein content and free proline content.
K1884	9.030	1.194	-0.173	Days to 50 per cent flowering, pods per plant, sound mature kernel per cent, 100 kernel weight, specific leaf area (SLA), haulm yield per plant, oil content, Protein content and free proline content.
Oil content				
K1809	48.40	0.726	-0.014	Days to 50 per cent flowering, pods per plant, sound mature kernel per cent, Kernel yield per plant, 100 kernel weight, SPAD chlorophyll meter reading (SCMR),specific leaf area (SLA), haulm yield per plant, oil content, Protein content and free proline content.
Anantha	48.40	0.550	0.041	Days to 50 per cent flowering, pods per plant, pod yield per plant, sound mature kernel per cent, kernel yield per plant, 100 kernel weight, SPAD chlorophyll meter reading (SCMR), specific leaf area (SLA), haulm yield per plant, oil content, Protein content and free proline content.