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Full Length Article

Simultaneous Selection for Stable Disease Resistant and High Yielding Groundnut Genotypes under High Rainfall Area

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Abstract

Groundnut (*Arachis hypogaea* L.) is a allotetraploid, self-pollinated crop valued for its high oil and protein content. Its haulm is used as a source of fodder. In addition, being a leguminous crop, it enriches the soil by fixing atmospheric Nitrogen. The traditional area under groundnut cultivation is endangered and is being gradually replaced by other commercial crops in high rainfall areas. High yielding genotypes which can perform stably from year after year are required to sustain the groundnut area. This is an attempt in groundnut to study simultaneously the role of weather, AMMI stability for pod yield and disease resistance. Thirteen best performing genotypes were evaluated for yield, leaf spot resistance and other agronomic traits during three consecutive years. This study helped in understanding the role of temperature and relative humidity in the increased expression of leaf spots and in turn reduction in pod yields. It also revealed that genotypes were highly influenced by the environment for pod yields while genotypes contributed more variation for disease score. Genotype × Environment Interaction (GEI) had a significant role for both pod yield and disease score. Simultaneous selection for high yield, yield stability, disease resistance and disease stability was best achieved when more weights were assigned to pod yield and disease score followed by yield stability and least weight to disease stability in the selection index. The best performing groundnut genotypes identified in the present study for high rainfall areas were K 1789, Kadiri 9 and TCGS 1097.

Keywords: AMMI; Groundnut; Leaf spot; Selection index; Simultaneous selection; Stability

Introduction

Groundnut (*Arachis hypogaea* L.) is a leguminous, self-pollinated allotetraploid crop cultivated from the tropical to temperate zones in the world. It is rich in edible oil (44 to 56%) and protein (22 to 30%). It is also rich minerals like P, Ca, Mg and K and vitamins; E, K and B. High-oleic-acid content in groundnut kernels Groundnut kernels with a high oleic acid concentration increase oil stability and give health benefits (Abady *et al*. 2021).

India leads the globe in acreage (55.6 lakh ha) and second in production (101 lac tonnes) with a productivity of 1816 kg/ha in 2020–2021 (agricoop.nic.in). In India, nearly 85 percent of groundnut cropped area is under rainfed and 80% of the rainfed area comes under dry lands where there is no availability of irrigation (Roy and Shiyani 2000). About 75% of the groundnut area in India is in a low to moderate rainfall zone (parts of the peninsular region, as well as the western and central areas) with a short distribution time (90–120 days) and 25% under high rainfall zone (http://www.agrometeorology.org/files-folder/repository / gamp_chapt13B.pdf). The area under this crop is fluctuating since cost of cultivation is high and yields are unpredictable especially in the areas which receive high rainfall like North Coastal Andhra Pradesh of India. Hence, farmers are slowly shifting to other remunerative crops like maize. This in turn resulted in decreased groundnut cropped area in high rainfall areas. The low pod yields of groundnut in high rainfall areas may be because of basal stem elongation. Pegs formed at basal node have more chances of penetration into the soil and thus forming fully matured pods compared to those at other nodes. When the basal stem itself elongates, the distance from the soil to the pegs formed at basal stem also increase and thus resulting in reduced pod yields in groundnut. Further, high rainfall leads to increased humidity which is much congenial for the occurrence of tikka leaf spot which in turn reduces yields up to 50% (Khedikar *et al*. 2010). This disease is caused by *Cercospora arachidicola* (Early leaf spot). *and Cercospora personata* (Late leaf spot). When proper measures were not

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taken, 50% yield losses were witnessed in the China due to early leaf spot (Geng *et al*. 2021). Previous studies on rainfall pattern and groundnut yields also indicate that the rainfall and groundnut production had a strong negative relationship (Pandya *et al*. 2019). Therefore, development of genotypes suitable for *Kharif* or summer-rainy season in high rainfall areas is a major challenging task and so far all the varieties released in India are mostly suited for *Rabi* or dry season in medium to high rainfall areas. Identification of high yielding, disease resistant and stable genotypes for high rainfall areas plays a crucial role in sustaining the groundnut cultivation in those areas which receive more than 1000 mm annual rainfall. Hence, the present study aimed at simultaneous selection of stable genotypes for high yield and disease resistance.

Materials and Methods

Experimental site, plant material and experimental design

Best performing thirteen advanced lines and released varieties of groundnut which proved to be promising at various other groundnut breeding research stations (Agricultural Research Station, Kadiri and Regional Agricultural Research Station, Tirupati) were collected for re-evaluation at Agricultural Research Station, Vizianagaram, Andhra Pradesh, India to find out the suitability and adaptability of genotypes in the region which receives an annual rainfall of 1100 mm (Table 1). This station is located at Latitude: 18.12' N, Longitude: 83.40' E and Altitude of 63 m. MSL, comprising red sandy loam soil. This location witnesses both, early leaf spot and late leaf spot regularly during *kharif* season. The experiment was conducted for three consecutive *kharif* seasons (rainy season of 2015, 2016 and 2017). Genotypes were grown in six rows of five-meter length in a randomized complete block design (RCBD) with three replications. All standard practices were followed (20-40-40 kg NPK/ha, N in two equal split doses, one at the time of sowing and second at 30 days after sowing) except for control of leaf spot disease so that the role of the environment on natural occurrence of disease and in turn its effect on yield could be studied.

Parameters and traits studied

Weather parameters like maximum and minimum temperature, relative humidity, cumulative rainfall and number of rainy days were recorded during three years cropping period. Data was recorded on nine quantitative traits: Days to 50% flowering; Plant height in cm; Number of Pods per plant; Number of branches per plant; Pod yield in t/ha; Shelling percent (%); Kernel yield in t/ha, Early leaf spot (%) and Late leaf spot (%). Disease score for early and late leaf spot were calculated at 60 and 90 days after sowing as percent disease index (PDI):

$$\mathrm{PDI} = \frac{\text{Number of diseased plants}}{\text{Total Number of plants}}$$

Statistical analysis

Pearson association analysis was performed using SPSS (v. 16). Combined analysis was performed in RStudio (RStudio Desktop version) after testing the error variance for homogeneity. AMMI (Additive Main Effect and Multiplicative Interaction) stability analysis, AMMI Stability Values (ASV) and simultaneous selection for high yield, yield stability, disease resistance and disease stability were calculated using agricolae package in R (Onofri and Ciriciofolo 2007) with little modification for simultaneous selection. Though disease score was recorded for both early and late leaf spot, the later was considered to assess the role of genotype × environment interaction (GEI) for disease occurrence and stability in expression of resistance or susceptibility by different genotypes. In general, early and late leaf spots were highly correlated and late leaf spot was considered to be more aggressive than early leaf spot causing heavy defoliation of leaves leading to losses in pod yield (http://osufacts.okstate. edu). The AMMI analysis was conducted only after observing more than 70% GEI signal for both traits in the pooled ANOVA. This is done to avoid wrong interpretations because, when the signal is low, noise will be more (Gauch 2013).

Stability for yield indicates consistent performance of genotypes, whether the genotype may be high yielding or low yielding similarly for disease, stability for disease implies consistent reaction of a genotype towards a virulent pathogen. It may show resistant or susceptible reaction but always the same. ASV was considered for calculation of simultaneous selection index because the model obtained was AMMI2 and ASV gives weighted values to principal components (PCs) based on their contribution to GEI (Purchase *et al.* 2000). The extended formula of Rao and Prabhakaran (2005) including disease score and stability for disease was used to identify better performing groundnut genotypes for high rainfall areas. The criteria is that a desirable genotype is the one which has high pod bearing ability along with high stability for yield, strong resistant reaction towards the disease and high stability for low/no disease:

$$\mathrm{I_i} = \alpha \frac{\overline{PY_{i\ldots}}}{\overline{PY}\ldots} + \beta \frac{\frac{1}{ASV_{PY_i}}}{\frac{1}{g}\sum_1^g \frac{1}{ASV_{PY_i}}} + \gamma \frac{\frac{1}{\overline{\overline{DS_{i\ldots}}}}}{\frac{1}{\overline{\overline{DS_{\ldots}}}}} + \delta \frac{\frac{1}{ASV_{DS_i}}}{\frac{1}{g}\sum_1^g \frac{1}{ASV_{DS_i}}}$$

Where

$\mathrm{I_i}$= Index of the i^{th} genotype.

$\overline{PY_{i\ldots}}$ = is the average pod yield of the i^{th} genotype during three years of testing

$\overline{PY}$ ...= the overall mean of pod yield,

ASV_{PY_i} =AMMI Stability Value of i^{th}genotype for pod yield

g= Number of genotypes

$\overline{DS_{i\ldots}}$= is the average disease score of the i^{th} genotype during three years of testing

$\overline{DS_{..}}$ = the overall mean of disease score

ASV_{DS_i} = AMMI Stability Value *of i^{th}* genotype for disease

α, β, ϒ and δ are the weights attached to pod yield, pod yield stability, disease score and disease score stability to arrive at an index of a genotype. Ranking of genotypes was based on the index score it attained among 13 genotypes studied.

Simultaneous selection analysis was conducted using different combinations giving different weights to different parameters, starting from equal weight to biased weight and even giving no importance to particular trait like disease stability or disease occurrence, so that best genotypes can be identified. Various combinations of weights tried were:

I_1: α=25, β=25, ϒ=25 & δ=25	I_6: α=40, β=15, ϒ=40 & δ=5	I_{11}: α=50, β=50, ϒ=0 & δ=0
I_2: α=40, β=20, ϒ=20 & δ=20	I_7: α=50, β=20, ϒ=30 & δ=0	I_{12}: α=60, β=40, ϒ=0 & δ=0
I_3: α=50, β=20, ϒ=20 & δ=10	I_8: α=50, β=10, ϒ=40 & δ=0	I_{13}: α=70, β=30, ϒ=0 & δ=0
I_4: α=50, β=20, ϒ=25 & δ=5	I_9: α=33, β=33, ϒ=33 & δ =0	I_{14}: α=80, β=20, ϒ=0 & δ=0
I_5: α=50, β=15, ϒ=30 & δ =5	I_{10}: α=40, β=30, ϒ=30 & δ=0	I_{15}: α=90, β=10, ϒ=0 & δ=0

Results

Role of weather on pod yield and disease occurrence

The amount of rainfall received during 2016 (Fig. 1) was more compared to other two years which might have resulted in higher plant height (Table 2). During 2016, maximum temperature was below 34°C and minimum temperature was nearer to 22°C with morning and afternoon relative humidity reaching more than 82% and near to 78% respectively which were congenial for tikka leaf spot. In order to have a better understanding on the influence of weather parameters on yield and other related traits, correlations were studied, and results revealed some significant associations (Table 3). Plant height as was assumed had significant positive association with rainfall while shelling percent had significant negative association with rainfall and plant height indicating that increase in plant height due to increased rainfall led to the production of poorly filled pods. Days to 50% flowering was not affected by the weather. Early leaf spot did not show any significant relationship with the weather parameters. However late leaf spot recorded significant positive association with number of rainy days and relative humidity recorded in the afternoon, as well as significant negative association with minimum temperature.

AMMI analysis

To understand the role of environment on the expression of yield and disease occurrence among various genotypes, AMMI analysis was conducted (Table 4). Results revealed that genotype, environment and G × E interaction were highly significant ($P < 0.01$) for both pod yield and disease occurrence. It was observed that for pod yield, the role of environment was high (43.1%) followed by genotypes (22.7%) and G×E interaction (21.4%) while for disease resistance the proportion of variation explained by genotypes (40.2%) and GEI (37.3%) was much more than that of environmental variation (14.7%). To include the stability parameter for yield, Rao and Prabhakaran (2005) suggested a model which was extended in the present study to include disease resistance and stability for disease and consequently simultaneous selection index was calculated.

Selection index

When only mean yield was considered for ranking, the genotypes, K 1789, TCGS 1097 and K 1801 ranked the best. The highly stable genotypes were ICGV 03057, Kadiri Harithandhra and TCGS 1097 (Table 5). When disease resistance was given main criterion for ranking, K 1789, Kadiri 9 and K 1805 were having least score. Since direct selection is not advisable, therefore selection index was developed with various weights assigned to yield(α), yield stability(β), disease resistance (Υ) and disease resistance stability (δ). Similar results were observed from various selection indices developed, for example in I_1 & I_2, the top best genotypes were common. Hence to avoid redundancy, similar selection indices were discussed as group. Only one sample from each group was presented in the Table 5.

I_1 & I_2: When equal weights were assigned to all factors or importance was given even to disease resistance stability and pod stability, the genotype, K 1789 with 2.10 t/ha average pod yield and 4.2% disease score ranked first, followed by Dharani with 1.47 t/ha pod yield and 40.1% disease score which in turn was followed by the genotype, ICGV 03057 with 1.37 t/ha pod yield and 40% disease score. The genotype, K 1789 with high pod yield and low disease score along with moderate yield stability is very much of interest. Though genotypes, Dharani and ICGV 03057 were nearer to or less than mean pod yield with high disease score, the undue weight given to stability for disease and stability for yield marked them as best genotypes. But practically, they cannot be selected because of higher disease pressure and lower average yield. The selection of genotypes.

I_3 & I_4: When the weight for pod yield increased and weight for disease stability was reduced but still giving importance to pod yield stability and disease resistance, here also the genotype, K 1789 stood as the best genotype which is followed by genotypes, Dharani and Kadiri 9. Though the genotype, Kadiri 9 had more pod yield (1.50 t/ha) and very less disease score (11.0%) than the genotype, Dharani (1.37 t/ha & 40% pod yield & disease score respectively), it ranked only after Dharani because pod yield stability and disease resistance were given almost equal importance. Hence, this may not be the good index for selection.

Table 1: List of groundnut genotypes and their pedigree

S. No.	Genotype	Pedigree	Origin	Type of genotype
1	K 1805	(ICGV92069 X ICGV93184) X (ICGS44 X ICGS76)	ARS Kadiri	Advanced breeding line
2	Kadiri 6	JL 24 × Ah 316/s	ARS Kadiri	Released variety
3	Dharani	VRI-2 × TCGP-6	RARS, Tirupati	Released variety
4	K 1725	Kadiri 7 bold x TAG24	ARS Kadiri	Advanced breeding line
5	Kadiri 9	Kadiri 4 x Vemana	ARS Kadiri	Released variety
6	TCGS 1097	TAG-24 × TCGS-522	RARS, Tirupati	Advanced breeding line
7	K 1789	(ICGV92069 X ICGV93184) X[(ICGV87121XICGV87853)X ICGV92093]	ARS Kadiri	Advanced breeding line
8	Kadiri Harithandra	9157-2xPI476177	RARS, Tirupati	Released variety
9	TCGS 1156	TAG-24 × Jyothi	RARS, Tirupati	Advanced breeding line
10	K 1801	ICGV96176 (Floriant X 2597447 XICGV88312)	ARS Kadiri	Advanced breeding line
11	Anantha	Vemana x Girnar	ARS Kadiri	Released variety
12	TCGS 1157	TAG-24 × Jyothi	RARS, Tirupati	Advanced breeding line
13	ICGV 03057	[{(F 334 A-B-14 x NC Ac 2214) x ICG 2241) x (ICGMS 42 x Kadiri 3)} x {(FESR 13x Chico) x (CS 9 x ICGS 5)}]	ICRISAT, Hyderabad	Advanced breeding line

Table 2: Mean performance of thirteen groundnut genotypes evaluated during *Kharif* 2015, 2016 and 2017

S. No.	Year	DFF	PH	NPD	NBR	PY	SP	KY	ELS	LLS
1	2015	31.7	62.8	19.9	6.1	1.96	70.8	1.40	11.4	23.2
2	2016	32.1	102.2	16.5	8.0	1.08	68.1	0.74	17.0	37.8
3	2017	25.2	67.6	11.1	4.7	1.31	70.9	0.91	20.7	30.6
Mean		29.7	77.5	15.8	6.3	1.45	69.9	1.02	16.4	30.5
SE (±)		0.53	0.32	2.03	0.55	0.19	0.43	0.40	1.54	0.53

DFF: Days to 50% flowering; PH: Plant height in cm; NPD: Number of Pods per plant; NBR: Number of branches per plant; PY: Pod yield (t/ha); SP: Shelling percent (%); KY: Kernel yield (t/ha), ELS: Early leaf spot (%) and LLS: Late leaf spot (%)

Table 3: Correlation of weather parameters with pod yield, disease score and other traits of 13 groundnut genotypes tested during *Kharif* 2015, 2016 and 2017

Trait	RF	RD	T_{max}	T_{min}	RH_M	RH_A	DFF	PH	NPD	NBR	PY	SP	KY	ELS
RD	0.990*													
T_{max}	0.748	0.645												
T_{min}	-0.935	-0.976*	-0.464											
RH_M	0.778	0.860	0.165	-0.950*										
RH_A	0.964*	.992**	0.546	-0.995**	0.916									
DFF	0.364	0.227	0.891	-0.010	-0.301	0.105								
PH	0.996**	0.973*	0.805	-0.899	0.718	0.937	0.447							
NPD	-0.072	-0.214	0.608	0.421	-0.682	-0.333	0.903	0.019						
NBR	0.803	0.709	0.996**	-0.539	0.250	0.617	0.848	0.853	0.537					
PY	-0.831	-0.902	-0.252	0.974*	-0.996**	-0.948	0.216	-0.777	0.615	-0.335				
SP	-0.973*	-0.929	-0.881	0.827	-0.611	-0.877	-0.570	-0.990*	-0.161	-0.919	0.679			
KY	-0.829	-0.900	-0.248	0.973*	-0.996**	-0.947	0.220	-0.775	0.618	-0.331	0.999**	0.676		
ELS	0.315	0.447	-0.395	-0.630	0.840	0.554	-0.770	0.227	-0.969*	-0.313	-0.789	-0.086	-0.792	
LLS	0.946	0.983*	0.493	-0.999**	0.939	0.998**	0.044	0.913	-0.390	0.567	-0.966*	-0.846	-0.965*	0.604

RF: Total rain fall received; RD: Total number of rainy days; T_{max}: Mean maximum temperature; T_{min}: Mean minimum temperature; $RH_{M\&A}$: Relative humidity recorded during morning and afternoon. DFF: Days to 50% flowering; PH: Plant height in cm; NPD: Number of Pods per plant; NBR: Number of branches per plant; PY: Pod yield (q/ha); SP: Shelling percent (%); KY: Kernel yield (q/ha), ELS: Early leaf spot (%) and LLS: Late leaf spot (%).

Table 4: Pooled ANOVA and AMMI ANOVA for groundnut yield and disease occurrence during *Kharif* 2015, 2016 and 2017

Source	Pod yield (q/ha)		% Variation explained	Disease score (%)	% Variation explained
	d.f	MSS		MSS	
Total	116	32.3		296.0	
Treatment Design	38	86.1		833.4	
Genotype	12	71.1***	22.7% of Total variation	1149.02***	40.2% of Total variation
Environment	2	809.0***	43.1% of Total variation	2528.2**	14.7% of Total variation
GE Interaction	24	33.4***	21.4% of Total variation	534.36***	37.3% of Total variation
IPC1	13	47.9***	77.6 of GE Interaction	882.37***	89.4 of GE Interaction
IPC2	11	16.3**	22.4 of GE Interaction	123.07***	10.6 of GE Interaction
Experimental Design	78	6.13		34.2	
Blocks within Environment	6	6.9		132.1	
Error	72	6.1		26.1	

d.f, degree of freedom; MSS, mean sum of squares: ***, significant at 0.1% ($P < 0.001$)

I_5 to I_{10}: Very little weight or no weight was assigned to disease stability and equal importance to all other components or slight increased weight to grain yield and disease resistance, as usual the genotype, K 1789 had highest index score followed by Kadiri 9 (1.53 t/ha & 11% pod and disease score respectively). In this case, though the

Table 5: Ranking of groundnut genotypes based on pod yield, yield stability, disease resistance and index-based ranking

Sr. No.	Genotype	PY	ASV_{PY}	DS	ASV_{DS}	Index Score						YBR	YSBR	DSBR	Index based Rank					
						I_1	I_3	I_7	I_{11}	I_{13}	I_{14}				I_1	I_3	I_7	I_{11}	I_{13}	I_{14}
1	K 1805	1.54	3.6	18.9	11.6	1.3	1.2	1.2	1.0	1.0	1.0	4	10	3	8	7	4	10	9	6
2	Kadiri 6	1.47	7.4	36.7	42.5	0.7	0.8	0.9	0.7	0.8	1.0	6	12	9	12	12	12	12	12	9
3	Dharani	1.21	1.7	40.1	02.1	2.7	1.7	1.0	1.3	1.1	0.9	11	4	10	2	2	9	5	6	11
4	K 1725	1.33	2.8	32.9	06.1	1.4	1.1	1.0	1.0	1.0	0.9	10	9	8	7	8	10	9	11	12
5	Kadiri 9	1.53	2.3	11.0	20.8	1.6	1.5	1.7	1.2	1.2	1.1	5	6	2	4	3	2	6	5	4
6	TCGS 1097	1.79	1.4	26.4	11.0	1.5	1.5	1.5	1.7	1.5	1.3	2	3	4	5	4	3	1	1	2
7	K 1789	2.1	2.5	4.2	06.9	3.2	2.8	3.4	1.4	1.4	1.4	1	7	1	1	1	1	4	2	1
8	KadiriHarithandra	1.16	1.4	30.0	07.8	1.5	1.3	1.2	1.5	1.2	0.9	12	2	6	6	6	6	3	4	10
9	TCGS 1156	1.00	7.7	50.9	20.0	0.6	0.6	0.6	0.5	0.6	0.7	13	13	13	13	13	13	13	13	13
10	K 1801	1.57	3.8	30.0	25.1	0.9	1.0	1.0	0.9	1.0	1.1	3	11	7	10	10	8	11	10	5
11	Anantha	1.39	2.6	45.9	23.9	0.9	0.9	0.9	1.1	1.0	1.0	7	8	12	11	11	11	8	8	7
12	TCGS 1157	1.35	2.3	29.9	13.6	1.1	1.1	1.1	1.1	1.1	1.0	9	5	5	9	9	7	7	7	8
13	ICGV 03057	1.37	1.3	40.1	05.6	1.7	1.4	1.2	1.7	1.4	1.1	8	1	11	3	5	5	2	3	3

where PY: Pod yield (t/ha); ASV_{PY}: AMMI stability value for pod yield; DS: Late leaf spot disease score (%); ASV_{DS}: AMMI stability value for disease score, YBR: Yield based rank; YSBR: Yield stability-based rank; DRBR: Disease score based rank

Index scores: I_1: α=25, β=25, Υ=25 & δ=25; I_3: α=50, β=20, Υ=20 & δ=10; I_7: α=50, β=20, Υ=30 & δ=0; I_{11}: α=50, β=50, Υ=0 & δ=0; I_{13}: α=70, β=30, Υ=0 & δ=0; I_{14}: α=80, β=20, Υ=0 & δ=0

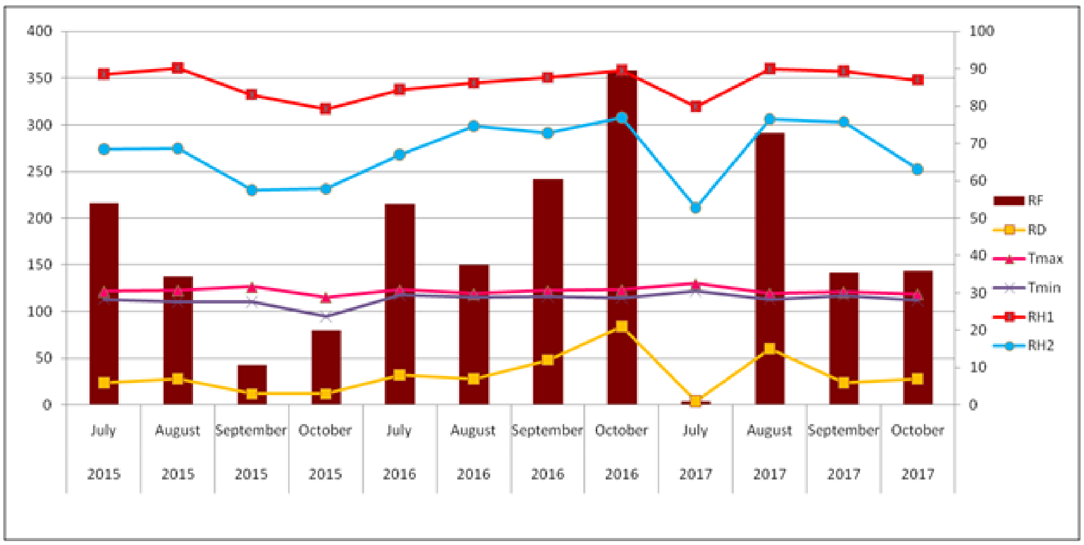

Fig. 1: Weather parameters during the groundnut crop growth period during *Kharif* season 2015, 2016 and 2017

where RF: Total rain fall received; RD: Total number of rainy days; T_{max}: Mean maximum temperature; T_{min}: Mean minimum temperature; $RH_{1\&2}$: Relative humidity recorded during morning and afternoon

Note: RF was depicted on primary axis and all others on secondary axis

genotype, TCGS 1097 (1.79 t/ha & 26.4% pod and disease score respectively) was having higher mean pod yield compared to Kadiri 9, but, less disease score of the later played an important role in ranking it as the second best genotype. Along with pod yield, disease resistance also plays a vital role, hence these results can be relied upon for selection of best genotypes. If the genotype shows resistant reaction during two years and breaks in one year than the average score may be lesser leaving an impression that it is moderately resistant to the disease but there is every chance to get the disease in future. Hence at least little importance should be given to disease stability also. In the present results, there were no such top-ranking genotypes with very less stability for disease. Therefore, a little weight or no weight given to disease stability did not affect the top three ranking genotypes. But, if anyone wishes to select a resistant genotype for inclusion in crossing programme then it is far more important to consider stability in expression of a genotype for disease resistance along with the less/no disease score.

I_{11}: It is similar to previous studies where only single trait, yield and its stability were considered. When yield and yield stability were given equal importance, TCGS 1097, ICGV 03057 and Kadiri Harithandra ranked the top three positions. Except TCGS 1097, ICGV 03057 and Kadiri Harithandra were lower than the average yield (1.45 t/ha) but were highly stable in their yield expression during the three periods of testing. Hence, they got best index score while K 1789 was no more in the scene though it had highest yield with moderate stability because of giving undue importance to stability when only two parameters are considered.

I_{12}& I_{13}: When only yield and its stability are under consideration, giving little more weight to yield compared to yield stability will choose stable and high yielding genotypes. The genotype, TCGS 1097 was the best with high yield and considerable stability. The genotype, K 1789 appeared as one among the best three but still ICGV 03057 which was a below average yielder is in the picture because of its high stability.

I_{14} & I_{15}: Even when very less weight is assigned to yield stability, ICGV 03057 had better index score and ranked third position indicating that comparative yield difference between ICGV 03057 (1.37 t/ha) and high yielding genotypes (K 1805, Kadiri 6, Kadiri 9 & K 1801 -1.54, 1.47, 1.53 & 1.57 t/ha respectively) was less compared to the stability score difference. Hence, if we are to consider only yield and stability then ICGV 03057 is considered to be better than K 1805, Kadiri 6, Kadiri 9 and K 1801, while TCGS 1097 is much better than ICGV 03057 for mean yield.

Discussion

The results showed that environment plays an important role in deciding the crop yield as well as disease occurrence. Hence, in the present study the role of weather parameters on pod yield and disease occurrence were also referred based on previous studies. With the increase in plant height due to basal stem elongation, the gynophores have to travel more distance to reach the soil. In this process of travelling long distances, nutrients may be exhausted before reaching the soil. This may result in reduced pod number and pod yield. In this regard, indirect selection for lesser plant height may be beneficial. But, it may be partially true. Taller plant height was observed during 2016 compared to 2015 and 2017, but, No. of pods in the year, 2016 were more than that of 2017. It may be because, pegs may reach the soil but, initial vigour required for formation of good size pods might be lost. The lower yields in 2016 can be further attributed to higher occurrence of late leaf spot disease which might have resulted in poor filling of pods. It is evident from low shelling percent recorded during 2016. Poor filling of pods due to decreased photosynthate production when the plant was affected by leaf spot disease. Favourable weather parameters like more than 70% relative humidity recorded twice a day, high maximum temperature during the crop growth period in the year, 2016 might have favoured the causal organism. It is in consonance with forewarning of tikka disease occurrence given by Samui *et al*. (2005). Whereas, Mangala and Padmapriya (2020) predicted that tikka disease will be more when there is prolonged heavy rainfall with relative humidity greater than 85% and temperature range between 26°C – 31°C.

The results obtained from the association studies were further supporting the findings of Samui *et al.* (2005) that decrease in minimum temperature and increase in relative humidity are the most important weather parameters to anticipate the occurrence of the leaf spot disease. But Jambhulkar (2016) observed that temperature was positively correlated and relative humidity was negatively correlated with the spore population. The positive significant association of late leaf spot with number of rainy days may not be direct. It may be that increased number of rainy days led to the increase in relative humidity as observed from their significant positive association which in turn enhanced the disease. The increase in disease in turn reduced pod yields significantly. Pod yields in this study did not show any significant association with rainfall rather it had a significant positive association with minimum temperature. It may be because groundnut requires warm temperature for proper growth and also decrease in minimum temperature increases leaf spot disease. Minimum temperature and relative humidity effected pod yields directly or indirectly through the disease occurrence. Disease can be forecasted based on the weather and preventive measures can be taken up but weather cannot be changed easily to get higher yields all the time. Therefore, it is better to select high yielding genotypes which perform consistently under varied situations. Selection of a better genotype is challenging since yields fluctuate from year to year even at a single location. This variation can be attributed to differences in factors like vegetative growth and/or disease occurrence.

Higher genotypic variation for disease resistance indicates that resistant genotypes can be developed through simple breeding techniques while the greater role of environment on pod yield indicates that stable high yielding groundnut genotypes are to be developed to withstand the vagaries of weather. Both pod yield and disease resistance emphasize the importance of the G × E interaction. Oteng-Frimpong *et al.* (2021) also observed to have significant genotype and G × E interaction variation in AMMI analysis for tikka disease. Similar results for pod yield were obtained by Badigannavar *et al.* (2007), Kebede and Getahun (2017), Ajay *et al.* (2020), Oteng-Frimpong *et al*. (2021) suggesting that pod yields are sensitive to weather fluctuations and there is a prerequisite to breed varieties for distinct regions since GEI was substantial. Dissection of GEI indicated that the first two interaction components in the ANOVA of AMMI2 model detailed 100% of the interaction variation leaving no residual (Table 4). This is in confirmation with Anuradha *et al*. (2017), which means that the first two interaction components could elucidate the interaction variation sufficiently and AMMI 2 model holds well (Gauch 2013).

AMMI analysis showed the sizeable role of G × E interaction for both pod yield and disease resistance indicating that genotypes cannot be selected *per se* and stability analysis component should be considered while selecting a better genotype. Selection of a genotype based on the mean performance and encouraging its cultivation in farmer's fields may lead to greater risk as the genotype may not perform consistently. At present it is not possible to predict the changes in weather accurately and select genotypes accordingly to suit the weather. The only alternative is to have a stable high yielding genotype with no/little compromise in yield and stability.

Simultaneous selection of genotypes for yield and yield stability were used by earlier researchers in groundnut (Ajay *et al*. 2020) and several other crops (Kumar *et al*. 2018 in chickpea, Anuradha *et al*. 2022 in finger millet) for identifying consistently better performing genotypes. Though, Oteng-Frimpong *et al*. (2021) performed stability analysis for both pod yield and disease score, they didn't use selection index to combine both the traits and their stability values for selecting genotypes. Faheem *et al*. (2021) utilized novel approach of GYT (Genotype × Yield × Trait) selection in wheat to simultaneously select all the traits studied, but didn't utilize stability indices in selection of genotypes. Inclusion of disease resistance and its stability in selection index assigning various weights is first of its kind in the present study. Careful selection of a model is very important. If one is having only yield and stability for yield, then it is better to give more weight to yield rather giving equal importance as it may lead to loosing of high yielding genotypes like K 1789. Here we need to remember one thing, for yield, ranking of genotypes may hold good but for stability the ASV values should be below average and rank is not important. Similarly, Anuradha *et al*. (2022) suggested to use culling method of simultaneous selection index for stability values.

Simultaneous selection index analysed with 15 different combinations of weights assigned to pod yield, yield stability, disease score and disease stability. High yielding genotypes along with high to moderate stability can be selected with some compromise on yield stability as observed in the selection indices, I_{12} to I_{15}. Whenever there is a possibility of having disease resistance data along with yield, it is more important to give due importance to disease reaction and some importance to stability for disease resistance along with more emphasis on yield and to some extent on yield stability for example in I_5 to I_{10}. The best scoring genotypes (K 1789, TCGS 1097 and Kadiri 9), were identified from best combination of weights.

Conclusion

This study revealed that temperature and relative humidity played a major role in the expression of leaf spot diseases. AMMI analysis for pod yield and disease resistance indicated that environmental influence was much more pronounced in the determination of pod yields whereas genotypes and G × E Interaction had equal role in the expression of the disease. Among all the selection indices developed, I_5 to I_{10} proved to be the best indices for identifying stable high-yielding, disease-resistant genotypes. Hence, by giving more weight to the mean performance of pod yield and disease score followed by yield stability and least weight for disease stability, the best groundnut genotypes identified in the present study for high rainfall areas were K 1789, Kadiri 9 and TCGS 1097.

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Author Contributions

NA designed, planned and executed the experiments and interpreted the results, prepared the original draft of manuscript, TSSKP supervised the experiments and reviewed the manuscript and AS, YSR and UT were engaged with yield trials and phenotypic data analyses.

Conflict of Interest Statement

All authors declare no conflicts of interest.

Data Availability Statement

The datasets generated during the study are all included in the manuscript. Further inquiries can be directed to the corresponding author.

Ethics Approval

Ethics approval was not required for this study.

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