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Study on Genetic Variability, Association and Classification of F_4 and F_5 Progenies of Groundnut (*Arachis hypogaea* L.) for Late Leaf Spot Reaction, Yield and its Component Traits

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Abstract

In the present study, F_4 and F_5 populations were evaluated to study the genetic variability for traits related to *per cent* disease incidence (PDI) for late leaf spot (LLS) reaction, pod yield and its component characters. Higher estimates of PCV and GCV were recorded for PDI at all the intervals, number of pods per plant, kernel yield per plant and pod yield per plant. High heritability accompanied with high GAM was observed for pods per plant, kernel yield per plant, pod yield per plant while plant height showed moderate GAM. Pods per plant, kernel yield per plant, sound mature kernel *per cent* and shelling *per cent* exhibited strong positive association with pod yield, whereas PDI@60 DAS, PDI@75 DAS, PDI@90 DAS and PDI@105 DAS exhibited significant negative association. Kernel yield exerted highest positive direct effect on pod yield. PDI at all the intervals recorded negative direct effect on pod yield. Indirect effect of number of pods per plant and kernel weight were high for pod yield. Principal component analysis (PCA) indicted that first and second component justified 58.4 *per cent* of variations among different traits. Biplot analysis of PCA results aided in identifying 15 LLS resistant lines. Kernel weight per plant has direct effect on pod weight per plant. Therefore, selecting this trait will increase pod yield. The identified lines can be evaluated in varied rainfed environments to exploit their disease resistance and yield potential and the validated lines can be utilised as improved cultivars.

Keywords : Association, Groundnut, Genetic variability, Late leaf spot disease, Principal component analysis

Groundnut (*Arachis hypogaea* L.) is one of the principal oil seed crops of the world. It is popularly known as 'King of oil seeds' because of its high edible oil content and it is utilized for human consumption as vegetable oil and protein and as fodder for livestock. It contains edible oil (44-53%), protein (23-25%), carbohydrate (20%) and fibre (3%). It is also rich in calcium, phosphorus, iron, thiamine (B1), riboflavin (B2) and niacin. Groundnut, being majorly grown in rainy season, is affected by several pests and diseases leading to lower productivity. Among several diseases affecting groundnut, late leaf spot disease caused by *Phaeoisariopsis personata* results in reduction in pod and haulm yield of 25.3 and 53.0 per cent, respectively (Eswara Reddy and Venkateshwara Rao, 1999). Many methods have been suggested to control LLS including combination of cultural and chemical measures, but they were of limited success. Genetic studies on LLS resistance suggested that resistance to this fungal disease is complex and polygenic in nature and sensitive to environments (Sujay *et al*., 2012). It has been long known that environment factors, like temperature and humidity are important affecting infection and development of LLS disease. Land races and wild species of groundnut possess high level of resistance to foliar diseases, but the resistance is generally linked to low productivity, late maturity, poor adaptability and undesirable pod features (Wynne *et al*., 1981 and Singh and Mass, 1982). Germplasm originating from secondary centers of diversity were resistant to foliar diseases with desirable agronomic backgrounds, but their productivity levels were low (Singh and Mass, 1982). Therefore, development of new varieties that are tolerant to LLS and high yielding cultivars suitable for cultivation is the need of the hour. In plant breeding, development of any variety requires suitable breeding method and for success of any crop improvement programme requires genetic variability in the initial breeding population is required. For practicing selection in the population, presence of genetic variability is a pre-requisite. For developing appropriate breeding strategy, information on phenotypic and genotypic variation for pod yield and its component traits is needed in order to practice selection. Breeders often use segregating generations as source population and exercise selection for identifying homozygous lines with better performance with a view to develop varieties. But pod yield being complex trait is dependent on a number of other traits. The traits that influence yield and their direct and indirect effects can be studied through correlation and path analysis. This becomes important in order to select the traits that indirectly influence yield. Therefore, a study was undertaken to estimate the genetic variability, heritability, correlation and path analysis for LLS reaction and pod yield related traits.

Material and Methods

The material used in the experiment consisted of two segregating populations of F_4 and F_5 generations, developed from the cross TMV 2 × GPBD 4. TMV 2, female parent of the cross is highly susceptible to LLS, whereas GPBD 4 is resistant to LLS. The initial objective of the study was to screen the population for LLS resistance and identify resistant/tolerant sources for LLS. Ninety four lines of F_4 generation were screened in *kharif* 2021 for LLS reaction and its yield component traits. Later the lines were forwarded to F_5 generation through progeny test and observations on pod yield related traits were recorded in summer 2022. The present investigation was conducted at experimental plots (K- block), Department of Genetics and Plant Breeding, College of Agriculture, GKVK, University of Agricultural Sciences, Bangalore. In *kharif* season F_4 population was grown in separate blocks along with checks and parents in augmented design as suggested by Federer (1959) and observations were recorded on each of the F_4 individuals. TMV 2 was used as a spreader row, since the variety is highly susceptible to LLS disease to create natural epiphytotic condition for the spread of the disease. It was replicated after an interval of six lines. LLS reaction was scored following modified 9 point scale for LLS disease given by Subrahmanyam *et al*. (1995) on 60^{th}, 75^{th}, 90^{th} and 105^{th} days after sowing till the crop reached physiological maturity. The data was analysed in R software *ver.* 4.2.1. Genotypic and phenotypic coefficients of variability were computed both in F_4 and F_5 generation for each character as per the method suggested by Burton and Devane (1953). Heritability was estimated in F_4 and F_5 generation for each character using the formula given by Lush (1945). Genetic advance was estimated using the formula of Johnson *et al*. (1955). Correlation coefficients were computed amongst the pairs of characters using the formula given by Panse and Sukhatme (1964). Principal Component analysis and biplot analysis were computed and biplot graph was plotted using XLSTAT © 2023. The lines were categorised based on the response into four groups (A, B, C and D) for LLS resistant and susceptibility.

Results and Discussion

Analysis of Variance (ANOVA) for LLS reaction, pod yield and its component traits of F_4 and F_5 generations of the cross TMV 2 × GPBD 4 is presented in Table 1 and Table 2. Mean sum of squares genotypes were significant for all the traits under study in F_4 population except for traits such as PDI@90 DAS, plant height and kernel yield per plant. In F_5 population, all traits studied were significant, except kernel yield. Analysis of variance for both progenies and checks displayed significantly greater difference for characters like PDI@60 DAS, PDI@75 DAS, PDI@105 DAS, days to first flowering, number of

TABLE 1

Mean sum of squares of F_4 progenies derived from the cross TMV 2 × GPBD 4 for pod yield and its attributing traits in groundnut

Source	Df	PDI@ 60 DAS	PDI@ 75 DAS	PDI@ 90 DAS	PDI@ 105 DAS	DFF	PH	PBP	NPP	PWP	NKP	KWP	SMK	SP
Treatment (ignoring Blocks)	96	0.55 *	1.5 **	2.39	2.88 **	4.68 **	10.93	34.96 **	83.68 **	30.69 *	320.6 **	12.01	68.76 **	173.08 **
Treatment: Check	2	4.61 **	22.01 **	23.47	23.94 **	22.23 **	9.75	2	360.29 **	255.55 **	1152.51 **	115.04 **	111.5 **	148.24
Treatment: Test vs. Check	1	15.96 **	6.12 **	1.57	0.06	0.04	0.43	14.61 **	21.24	200.54 **	121.75	97.61 **	3.84	0.09
Treatment: Test	93	0.3	1.01 *	1.94	2.46 **	4.35 **	11.07	35.89 **	78.4 **	24.03 *	304.85 **	8.87	68.54 **	175.48 **
Block (eliminating Treatments)	6	0.27	0.26	0.53	0.28	0.54	9.51	4.92 *	53.13	22.5	198.51 *	20.1 *	22.87	131.3 *
Residual	12	0.2	0.36	0.35	0.15	1.07	5.18	1.13	18.19	9.22	48.81	5.97	12.47	43.32

Df = Degrees of freedom, DFF = Days to first flowering, PH = Plant height (cm), PBP = Primary branches per plant, NPP = Number of pods per plant, PWP = Pod weight per plant (g), NKP = Number of kernel per plant, KWP = Kernel weight per plant (g), SMK = Sound mature kernel *per cent* (%), SP = Shelling percentage (%), *Significant @P = 0.05, **Significant @P = 0.01

TABLE 2

Mean sum of squares of F_5 progenies derived from the cross TMV 2 × GPBD 4 for pod yield and its attributing traits in groundnut

Source	Df	DFF	KWP	NKP	NPP	PBP	PH	PWP	SMK	SP
Treatment (ignoring Blocks)	96	19.05 *	8.56	373.35 **	99.4 **	3.07 *	16.77 **	28 *	120.12 **	214.33 **
Treatment: Check	2	3.83	109.04 **	1396.99 **	458.81 **	2.1	5.09	285.18 **	177.81 **	123.7
Treatment: Test vs. Check	1	8.81	103.44 **	20.33	15.34	0.03	108.93 **	96.69 **	524.75 **	0.4
Treatment: Test	93	19.49 *	5.38	355.13 **	92.57 **	3.12 *	16.03 **	21.73	114.53 **	218.58 **
Block (eliminating Treatments)	6	2.02	13.79 *	150.74	38.57	5.32 *	6.09	14.04	26.63	141.45 *
Residual	12	6.26	3.91	54.69	22.27	1.18	3.6	9.52	11.02	40.26

Df = Degrees of freedom, DFF = Days to first flowering, PH = Plant height (cm), PBP = Primary branches per plant, NPP = Number of pods per plant, PWP = Pod weight per plant (g), NKP = Number of kernel per plant, KWP = Kernel weight per plant (g), SMK = Sound mature kernel *per cent* (%), SP = Shelling percentage (%), *Significant @P = 0.05, **Significant pods per plant, pod yield per plant, number of kernel per plant, kernel yield per plant, sound mature kernel *per cent* except plant height, primary branches per plant and shelling percentage in F_4 generation. Mean sum of squares of checks *versus* progenies also recorded significant difference for all the characters except PDI@90 DAS, PDI@105 DAS days to first flowering, plant height, number of pods per plant, sound mature kernel *per cent* and shelling *per cent*. Non-significant variation was observed for kernel yield per plant for mean sum of squares of progenies in F_5 generation and there was no significant variation in case of progenies *versus* checks for shelling *per cent* in both the generations. The results obtained are in accordance with Bhavya *et al*. (2017) who recorded non-significant variation for traits pods/ plant and shelling *per cent* in progenies of F_4 generation and non-significant variation for days to first flowering and shelling *per cent* in F_5 population of the cross GKVK-16 × KCG-2. ANOVA revealed presence of significant variation for most of the characters under study among progenies except for kernel yield per plant thus indicating presence of sufficient amount of genetic variability for the traits under consideration.

Genetic Variability Parameters

Variability refers to presence of a wide range of phenotypic and genotypic differences among the genotypes of the population. These differences can be due to the differences in genetic constitution of the individuals or due to environment influence on the traits. In order to carry out selection in any population presence of variability is a must. Therefore, knowledge about the magnitude of genetic variability in a given population is of prime importance to plant breeders. Information of phenotypic and genotypic coefficients of variation provides the actual variance of the characters. Heritability and genetic advance estimation provides information about the genetic gain when selection is applied. In this study, variability parameters such as phenotypic (PCV) and genotypic coefficients of variation (GCV), heritability and genetic advance over *per cent* mean (GAM) were estimated.

The range of variation was wide for all the characters under study. Important pod yield component traits such as number for pods per plant recorded a wide range of 9.9 to 49.5 and 8.8 to 47.6 in F_4 and F_5 population, respectively. Traits such as pod yield per plant recorded range of 4.5 g to 28.6 g in F_4 generation and 3.6 g to 26.5 g in F_5 generation. Sound mature kernel *per cent* ranged between 44.6 to 89.8 per cent and 33.7 to 86.0 per cent in F_4 and F_5 population, respectively.

Estimates of genetic variability revealed high PCV and GCV for PD1@75 DAS (27.7 and 22.2 %), PD1@90 DAS (29.9 and 27.1 %) and PD1@105 DAS (28.1 and 27.3 %). Similar results of high PCV and GCV were recorded by John *et al*. (2006) for late leaf spot disease. Medium GCV estimates were recorded for PD1@60 DAS. Days to first flowering and plant height exhibited low to medium PCV and GCV estimates. Ganesan and Sudhakar (1995), John *et al*. (2006), Raut *et al*. (2010), Hiremath *et al*. (2011), Vishnuvardhan *et al*. (2012) and Zongo *et al*. (2017) also reported moderate estimates of PCV and GCV for plant height. Number of pods per plant, pod yield per plant, number of kernel per plant and shelling *per cent* recorded high estimates of PCV and GCV in F_4 and F_5 generations. The present findings were in accordance with results obtained by Venkataravana *et al*. (2000), Khote *et al*. (2009), Patil *et al*. (2014), Hyndavi (2015), Padmaja *et al*. (2015), Kadam *et al*. (2017), Patel (2017), Zongo *et al*. (2017) and Jambagi and Savithramma (2020) for pod yield and its component traits. Sound mature kernel percentage recorded medium to high PCV and GCV estimates in both the generations. Hugar and Savitramma (2015) recorded high PCV and GCV estimates for sound mature kernel percentage. Presence of high phenotypic and genotypic variation indicates that there is sufficient amount of variability present in the population and selection can be practiced. Lower estimates of PCV and GCV indicates lower magnitude of variation for these traits. Selection will be ineffective when the trait is not heritable or less heritable. Therefore, information on the magnitude of trait heritability is of prime importance for groundnut crop improvement. In this study, high broad sense heritability and genetic advance over *per cent* mean (GAM) was recorded for PD1@75 DAS (64.3 and 36.7 %), PD1@90 DAS (82.2 and 50.8 %), PD1@105 DAS (93.8 and 54.5 %), primary branches per plant, number of pods per plant, number of kernel per plant, sound mature kernel *per cent* and shelling *per cent* in both F_4 and F_5 generations. A similar trend was noticed by John *et al*. (2006) and Giri *et al*. (2009). Verma *et al*. (2002), John *et al*. (2007), Raut *et al*. (2010), Hyndavi (2015), Kumar *et al*. (2016) and Zongo *et al*. (2017) who reported high heritability coupled with high GAM for number of branches per plant, number of pods per plant, pod yield per plant and kernel yield. Medium heritability and GAM was recorded for PD1@60 DAS (32.0 and 13.7 %), plant height (53.2 and 10.5 %) and kernel yield per plant (32.7 and 26.4 %) in F_4 generation, whereas medium and low heritability was exhibited by pod yield per plant (56.2 and 37.1 %) and kernel yield per plant (27.3 and 16.8 %) in F_5 generation, respectively. The present results were in accordance with results obtained by Jayabose *et al*. (2022) who observed moderate genetic advance for kernel yield. Medium GAM was recorded by days to first flowering (19.5 %), plant height (18.1 %) and kernel yield per plant (16.8 %) in F_5 generation (Table 3).

Correlation Analysis

Correlation is the association between the traits and the information about correction allows breeders to practice selection for suitable traits that improve yield. Traits that show positive correlation can be selected in the breeding program for improvement of yield.

TABLE 3

Estimates of genetic variability parameters for late leaf spot disease reaction, pod yield and its component traits in F_4 and F_5 generations of cross TMV 2 × GPBD 4

Trait	Generation	Mean ± SE	Maximum	Minimum	GCV (%)	PCV (%)	h2bs (%)	GA	GAM (%)
PDI@ 60 DAS	F_4	2.64 ± 0.06	3.7	1.9	11.7	20.8	32.0	0.4	13.7
PDI@ 75 DAS	F_4	3.63 ± 0.11	5.6	2.3	22.2	27.7	64.3	1.3	36.7
PDI@ 90 DAS	F_4	4.66 ± 0.14	7.6	3.5	27.1	29.9	82.2	2.4	50.8
PDI@ 105 DAS	F_4	5.57 ± 0.16	8.3	4.1	27.3	28.1	93.8	3.0	54.5
DFF	F_4	32.43 ± 0.22	36.5	27.9	5.6	6.4	75.4	3.2	10.0
	F_5	31.7 ± 0.16	35.9	28.6	11.5	14.0	67.9	6.2	19.5
PH	F_4	34.86 ± 0.36	42.3	26.8	7.0	9.5	53.2	3.7	10.5
	F_5	35.3 ± 1.56	45.6	27.7	10.0	11.3	77.5	6.4	18.1
PBP	F_4	7.76 ± 0.61	10.9	4.6	76.0	77.2	96.9	12.0	54.3
	F_5	6.8 ± 0.36	10.6	3.4	20.6	26.2	62.1	2.3	33.5
NPP	F_4	7.34 ± 0.88	49.5	9.9	28.4	32.4	76.8	14.0	51.3
	F_5	28.7 ± 1.23	47.6	8.8	29.3	33.6	76.0	15.1	52.6
PWP	F_4	13.99 ± 0.49	28.6	4.5	27.5	35.0	61.6	6.2	44.6
	F_5	14.6 ± 0.78	26.5	3.6	24.0	32.0	56.2	5.4	37.1
NKP	F_4	51.74 ± 1.74	94.6	16.9	30.9	33.7	84.0	30.3	58.5
	F_5	54.5 ± 0.27	89.9	15.6	31.8	34.6	84.6	32.9	60.4
KWP	F_4	8.7 ± 0.39	15.8	2.1	22.4	39.1	32.7	2.0	26.4
	F_5	12.6 ± 1.67	15.6	2.4	15.6	29.8	27.3	1.3	16.8
SMK	F_4	75.83 ± 0.81	89.9	44.7	9.9	10.9	81.8	14.0	18.4
	F_5	71.6 ± 0.25	86.1	33.7	14.2	15.0	90.4	20.0	27.9
SP	F_4	55.3 ± 1.64	82.1	30.4	20.8	24.0	75.3	20.6	37.2
	F_5	55.5 ± 1.23	87.2	33.6	24.1	26.6	81.6	24.9	44.8

DFF = Days to first flowering PH = Plant height (cm) PBP = Primary branches per plant NPP = Number of pods per plant PWP = Pod weight per plant (g) NKP = Number of kernel per plant KWP = Kernel weight per plant (g) SMK = Sound mature kernel *per cent* (%) SP = Shelling percentage (%)

Thus correlation studies help in indirect selection of characters that affect yield.

PD1@60 DAS, PD1@75 DAS, PD1@90 DAS and PD1@105 DAS recorded significant negative association with traits such as number of pods per plant, pod weight per plant, number of kernel per plant, kernel yield per plant, sound mature kernel *per cent* and shelling *per cent*, whereas PD1@75 DAS exhibited non-significant negative correlation for sound mature kernel *per cent* in both the generations. Days to first flowering, plant height and primary branches per plant recorded negative and non-significant association with PDI at all the intervals. Similar results were reported by Vasanthi *et al*. (1998) who recorded negative association of late leaf spot with days to first flowering. Present results are also in accordance with Giri *et al*. (2009) who observed negative significant correlation between late leaf spot severity (%) and pod yield related traits in groundnut genotypes. Similarly, Yashaswini *et al.* (2021) recorded significant negative correlation of PDI at all the intervals to pod yield related traits in F_4 generation of groundnut cross TMV 2 × ICGV 86699. Important pod yield component traits such as number of plants, number of kernel per plant, kernel weight per plant and sound mature kernel per cent recorded significant positive correlation for pod yield per plant in both F_4 and F_5 generations (Table 4). The present results were in accordance with Lakshmidevamma *et al*. (2004), Dandu *et al*. (2012), Nandini and Savitramma (2012), Prabhu *et al*. (2014) and Jayabose *et al*. (2022) where they observed positive significant association between kernel yield, number of pods per plant, pod yield and shelling percentage. Shelling *per cent* exhibited non-significant positive correlation for number of pods per plant (0.1818), pod yield per plant (0.0991) and number of kernel per plant (0.1717) in F_4 generation. Similar results were reported by Shoba *et al*. (2012) and Prabhu *et al*. (2015).

Shelling *per cent* recorded negative non-significant correlation for number of pods per plant (0.1074) and number of kernel per plant (-0.1295), whereas negative significant association was seen between shelling *per cent* and pod weight per plant (-0.2713) in F_5 generation. Days to first flowering, plant height and primary branches per plant had non-significant positive correlation with number of pods per plant, pod weight per plant and kernel weight per plant. In the study conducted by Jayabose *et al*. (2022), pod yield and days to flowering, number of pods and kernel weight, shelling percentage and pod yield were negatively correlated.

Path Analysis

Correlation analysis provides the mutual relationship between various plant characters and determines the component character on which selection can be based for genetic improvement in yield. Path analysis splits the correlation coefficients into direct and indirect effects. Path analysis showing direct and indirect effects can be employed to get high simultaneous selection response for several characters from a diverse population. Therefore, path coefficient analysis could provide a more realistic picture of the interrelationship (Memon *et al*., 2019).

Direct Effects on Pod Yield Per plant

Number of pods per plant, kernel weight per plant, sound mature kernel *per cent* and shelling *per cent* recorded positive direct effect on pod yield per plant in both F_4 and F_5 population (Table 5). The results indicate that selection for these traits will positively improve pod yield. Similar results were reported by Lakshmidevamma *et al*. (2004) and Giri *et al*. (2009). In F_4 generation, PDI@60 DAS (-0.0007), PDI@75 DAS (-0.0271), PDI@90 DAS (-0.5542) and PDI@105 DAS (-0.2600) exhibited negative direct effects on pod yield per plant. Selection of genotypes with low PDI will be suitable in order to increase pod yield. In the study conducted by Giri *et al*. (2009), late leaf spot disease severity exerted negative direct on pod yield per plant. Other studies conducted by Sumanthi and Muralitharan (2007) and Shoba *et al*. (2012), Kushwah *et al*. (2016), Jahanzaib *et al*. (2020) and Jayabose *et al*. (2022) supported the above results.

Indirect Effects on Pod Yield Per plant

Indirect effect of number of pods per plant on pod yield per plant is significantly positive in both F_4

TABLE 4

Association analysis for LLS disease reaction, growth parameters, pod yield and its attributing traits in F_4 and F_5 generations of cross TMV 2 × GPBD 4

Traits	Gen.	PDI @60 DAS	PDI@ 75 DAS	PDI @ 90 DAS	PDI @ 105 DAS	DFF	PH	PBP	NPP	PWP	NKP	KWP	SMK	SP
PDI@ 60 DAS	F_4	1	0.7016 ***	0.5707 ***	0.6364 ***	-0.1884	-0.0356	0.0824	-0.4609 ***	-0.5309 ***	-0.4738 ***	-0.5454 ***	-0.2325 *	-0.2929 *
PDI@ 75 DAS	F_4		1	0.9175 ***	0.8899 ***	-0.1098	-0.0769	-0.0473	-0.6040 ***	-0.6260 ***	-0.5979 ***	-0.5300 ***	-0.2923	-0.1354 *
PDI@ 90 DAS	F_4			1	0.8888 ***	-0.1128	-0.0728	-0.0772	-0.5198 ***	-0.5562 ***	-0.5032 ***	-0.4080 ***	-0.2412 **	-0.0218 *
PDI@ 105 DAS	F_4				1	-0.0984	-0.0965	-0.0012	-0.5876 ***	-0.6073 ***	-0.5860 ***	-0.4965 ***	-0.3627 **	-0.1190 *
DFF	F_4					1	-0.0051	-0.0313	0.0042	-0.0256	-0.0085	0.1112	-0.061	0.2031 *
	F_5					1	0.0168	-0.1258	-0.0544	-0.0864	-0.0484	-0.0753	-0.0497	0.0083
PH	F_4						1	-0.0745	0.1482	0.1188	0.1248	0.1952	-0.0317	0.1265
	F5						1	0.1350	0.0584	0.1170	0.0616	-0.2268 *	0.1245	-0.4439 ***
PBP	F_4							1	0.0556	-0.048	0.0473	-0.1024	0.005	-0.1207
	F_5							1	-0.1566	-0.1495	-0.1688	-0.1750	-0.1678	-0.1372
NPP	F_4								1	0.9153 ***	0.9942 ***	0.7855 ***	0.6164 ***	0.1818
	F_5								1	0.8649 ***	0.9924 ***	0.7096 ***	0.8634 ***	-0.1074
PWP	F_4									1	0.9182 ***	0.7944 ***	0.5447 ***	0.099
	F_5										0.8687 ***	0.6632 ***	0.7700 ***	-0.2713 **
NKP	F_4										1	0.7804 ***	0.6336 ***	0.1717
	F_5											0.6810 ***	0.8837 ***	-0.1295
KWP	F_4											1	0.3554 ***	0.6500 ***
	F_5											1	0.5000 ***	0.4625 ***
SMK	F_4												1	0.0441 **
	F_5													0.2928 **
SP	F_4													1
	F_5													1

DFF = Days to first flowering; PH = Plant height (cm); PBP = Primary branches per plant; NPP = Number of pods per plant PWP = Pod weight per plant (g); NKP = Number of kernel per plant; KWP = Kernel weight per plant (g); SMK = Sound mature kernel *per cent* (%); SP = Shelling percentage (%);
*Significant @P = 0.05; **Significant @P = 0.01; *** Significant @P = 0.001

TABLE 5
Phenotypic path coefficient analysis indicating direct and indirect effect on LLS, pod yield and its attributing traits in F_4 and F_5 generations of cross TMV 2 × GPBD 4

Traits	Gen.	NPP	KWP	SMK	PDI@60 DAS	PDI@75 DAS	PDI@90 DAS	PDI@105 DAS	PWP
NPP	F_4	0.0016	1.0011	0.0002	0.0004	0.0023	-0.0008	-0.0005	0.5056 **
	F_5	1.3033	0.2008	0.0152	-	-	-	-	0.4951 **
KWP	F_4	1.0042	0.0013	0.0013	0.0022	0.0091	-0.0008	0.0016	0.4043 *
	F_5	0.0013	0.0086	0.0060	-	-	-	-	0.1094 *
SMK	F_4	0.0047	-0.0002	0.0111	0.0031	-0.0001	0.0012	0.0058	0.0838 **
	F_5	0.0013	0.0071	0.0281	-	-	-	-	0.2616 *
PDI@60 DAS	F_4	0.0026	0.0014	-0.0001	-0.0007	0.0030	-0.0002	0.1747	-0.1952 **
PDI@75 DAS	F_4	-0.2839	0.0005	0.0223	0.1324	-0.0271	0.0001	0.0841	-0.0943 *
PDI@90 DAS	F_4	-0.0736	-0.2452	0.0085	-0.0123	0.0030	-0.5542	-0.0084	-0.9315 *
PDI@105 DAS	F_4	-0.1359	-0.0856	0.0378	0.0649	0.0555	0.0820	-0.2600	-0.5341 *

DFF = Days to first flowering, PH = Plant height (cm), PBP = Primary branches per plant, NPP = Number of pods per plant, PWP = Pod weight per plant (g), SP = Shelling percentage (%), NKP = Number of kernel per plant, *Significant @P = 0.05, KWP = Kernel weight per plant (g), **Significant @P = 0.01, SMK = Sound mature kernel *per cent* (%)

(0.5056) and F_5 (0.4951) generations. Number of pods per plant recorded positive indirect effect on pod weight per plant through kernel weight per plant (1.0011 and 1.3013) and sound mature kernel *per cent* (0.0002 and 0.0152) in F_4 and F_5 generations. Kernel weight per plant exhibited positive indirect effect through number of pods per plant (1.0042 and 1.3116) and sound mature kernel *per cent* (0.0013 and 0.0152) in F_4 and F_5 populations. In the study conducted by Jayabose *et al*. (2022), number of pods had indirect effect on number of pods per plant contributing to kernel yield. Similarly, Patil *et al*. (2014) and Pachauri and Sikarwar (2022) recorded moderate indirect effect on kernel yield through number of pods. In conclusion, the traits kernel yield per plant, number of pods per plant exhibited positive direct effect on pod yield per plant. LLS disease incidence recorded significant negative indirect effect on pod yield per plant. Giri *et al*. (2009) in their study recorded negative indirect effect on pod yield per plant. Therefore, selection should be based on number of pods per plant and kernel yield per plant is more effective. Selection for low PDI will aid in development of lines resistance LLS and to increase pod yield in the population.

Principal Component and Biplot Analysis

Principal Component analysis is a method to find the linear combination that accounts for as much as variability as possible. In the present study principal component (PC) analysis was carried out to group genotypes of groundnut into different categories based on the mean performance for reaction to LLS. For the classification of lines on the basis of PDI@90, biplot was drawn using XLSTAT *ver*. 2023. Genotypes were grouped into different groups and is displayed in biplot of PCA1 and PCA2 (Fig. 1)

Combination of PC1 and PC2 explained highest amount of variation of 58.4 per cent (Table 6), mainly distinguishing the lines into four groups, out of which group C had high PDI@90 DAS. Other groups showed strong correlation between kernel weight per plant and shelling percentage. Significant correlation recorded for number of pods per plant, pod weight per plant and sound mature kernel percentage. Genotypes were categorised into four groups (A, B, C and D) based on their disease reaction.

Group A – resistant lines with low 90@PDI DAS with high shelling percentage and kernel weight per plant.

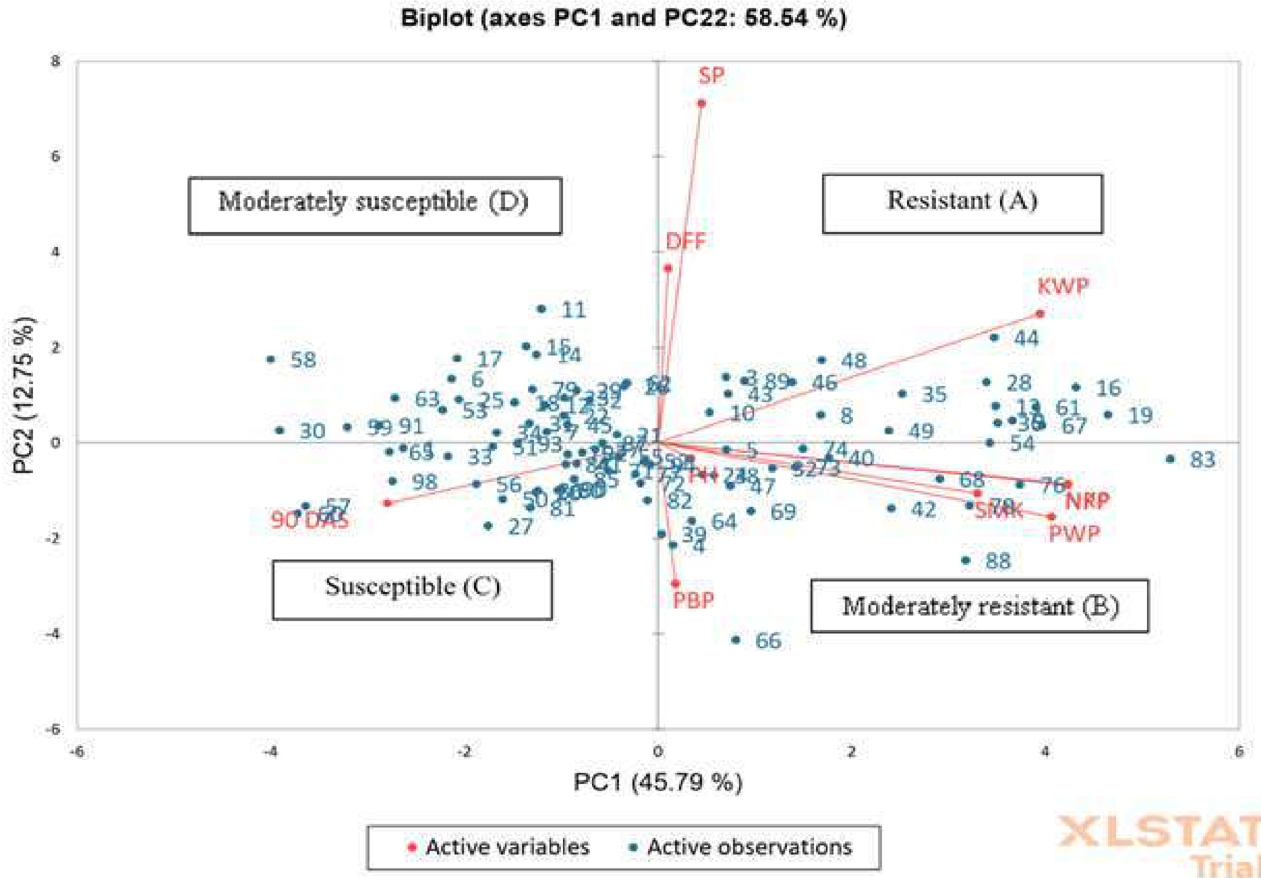

Fig. 1 : Grouping of the genotypes and identification of LLS resistant lines using Biplot analysis

Table 6

Estimates of eigen values and percentage of variation in F_4 population of cross TMV2 × GPBD4 in groundnut

Principal component values	Eigen value	Variability (%)	Cumulative %
PC1	4.579	45.795	45.795
PC2	1.275	12.750	58.544
PC3	1.065	10.647	69.192
PC4	0.950	9.495	78.687
PC5	0.923	9.226	87.913
PC6	0.759	7.589	95.501
PC7	0.310	3.105	98.606
PC8	0.119	1.194	99.800
PC9	0.017	0.174	99.974
PC10	0.003	0.026	100.000

Group B – moderately resistant and had high pod number, pod weight and SMK *per cent*. Group C – susceptible lines with high 90@PDI and group D with moderate susceptibility and is graphically represented in biplot. Our results showed that lines *viz*., 13, 16, 19, 28, 32, 36, 43, 45, 47, 54, 61, 67, 68, 78 and 83 were highly resistant and high yielding (Table 7 and Fig. 2).

Similar result was reported in safflower by Bahrami and Karimi (2014) in Tomato by Thi (2016) and Suresh *et al*. (2018) and in Groundnut by Savita *et al*. (2014) and Jambagi *et al*., 2020. In our study, high GCV, h^2 and GAM was observed for pod yield and its component traits which indicate additive gene action and is amenable for selection. Since characters *viz*., number of pods per plant, kernel weight per plant and SMK *per cent* had significant positive effect on pod weight per plant, these traits can be considered as

TABLE 7

Promising genotypes from the cross TMV2 × GPBD4 for LLS resistance and pod yield related traits

Genotype	DFF	PH	PBP	NPP	PWP	NKP	KWP	SMK	SP
13	32.4	28.6	8.5	37.6	21.5	73.5	13.5	82.6	62.79
16	34.3	34.6	6.9	42.9	22.7	81.3	14.5	83.1	63.88
19	29.8	41.3	10.4	45.7	21.4	89.6	15.6	83.9	72.90
28	34.5	39.6	8.5	40.6	19.5	76.9	13.2	81.0	67.69
32	31.2	35.6	4.8	32.7	15.5	61.2	7.5	79.2	48.39
36	31.2	34.5	7.5	42.1	20.3	80.4	12.6	78.0	62.07
43	34.6	32.4	7.5	26.5	14.5	50.6	8.5	76.1	58.62
45	31.5	36.5	8.5	20.4	11.5	38.5	6.68	68.8	58.09
47	32.4	36.5	7.2	28.5	16.5	55.5	8.9	74.8	53.94
54	30.4	41.2	9.3	38.6	21.5	74.5	13.2	82.1	61.49
61	30.6	36.7	6.4	37.8	23.7	73.2	15.8	82.7	66.67
67	34.5	38.3	6.1	41.4	23.6	79.5	12.6	82.4	53.39
68	31.2	30.5	5.9	38.7	22.5	74.6	10.5	81.0	46.67
78	34.2	38.7	6.8	42.3	23.7	81.5	10.9	82.0	45.99
83	32.8	32.7	6.3	49.5	28.6	94.6	14.5	84.1	50.78

DFF = Days to first flowering PH = Plant height (cm) PBP = Primary branches per plant NPP = Number of pods per plant
PWP = Pod weight per plant (g) NKP = Number of kernel per plant KWP = Kernel weight per plant (g)
SMK = Sound mature kernel *per cent* (%) SP = Shelling percentage (%)

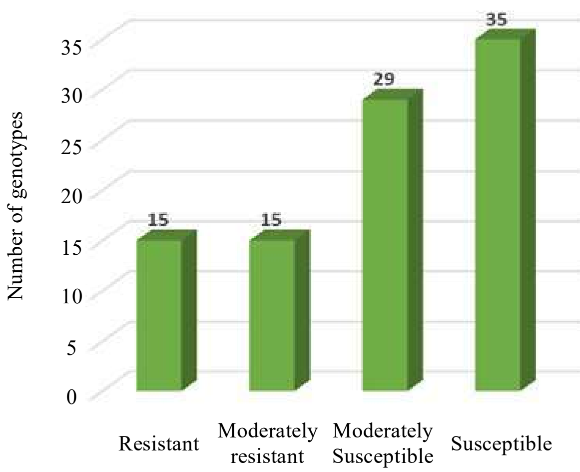

Fig. 2 : Classification of the genotypes into different disease reaction

important selection criteria for improving pod yield in groundnut. The resistant genotypes identified could be used as a potential source of resistance to LLS in groundnut improvement programme.

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