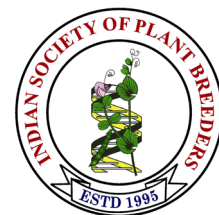# Electronic Journal of Plant Breeding

Research Note

Principal component analysis and genetic correlation studies in *Lens culinaris* Medik.

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Abstract
Lentil (*Lens culinaris* Medik.), an important *rabi* pulse crop grown in the plains of West Bengal, is vulnerable to Stemphylium blight, caused by the fungal pathogen *Stemphylium botryosum*. Considering the severity of the disease in the existing cropping system, an experiment was undertaken at the instructional farm of Uttar Banga Krishi Viswavidyalaya during *Rabi* 2021 with the objective to observe the correlation between the quantitative traits and the Area Under Disease Progress Curve (AUDPC) among the 50 lentil genotypes under the incidence of Stemphylium blight. The experiment was planned in Alpha Lattice design with two replications. The disease parameter AUDPC was derived from Hashemi's disease score. A total of twenty quantitative traits *viz*., days to 50% flowering, plant height, primary branches/ plant, secondary branches/ plant, nodes/ plant, leaflet number, leaflet length, leaf length, tendril length, peduncle length, 100 - seed weight, seed width, seed thickness, seeds/ pod, pods/ cluster, pods/ plant, days to maturity, pod yield, harvest index and seed yield were recorded. Significant positive correlation was recorded for AUDPC with days to 50% flowering and primary branches/ plant as against significant negative correlation for AUDPC with 100- seed weight and harvest index. The study on Principal Component Analysis (PCA) revealed that the traits *viz*., seed yield, pod yield, leaf length, leaflet length, pods/ plant, secondary branches, seeds/ pod, days to maturity, AUDPC, nodes/ plant, days to 50% flowering, pods/ cluster, seed thickness and harvest index showed the maximum contribution towards variation (19.49%) among the PC1 variables. The PCA biplot revealed that seed yield and pod yield strongly influenced PC1. Thus, the findings of the current study might be helpful to schedule the crop improvement program as far as the response of the crop to the disease is concerned.

Keywords: AUDPC, Correlogram, Lentil, PCA, Stemphylium blight.

Lentil (*Lens culinaris* Medik.) is an autogamous diploid legume crop with the chromosome number 2n=2x=14. It is a cost effective *rabi* pulse grown worldwide primarily for food, feed and soil health improvement. Global lentil productivity has increased from 806 kg/ha to 1194 kg/ha in recent decades. The national productivity of lentil records at 901 kg/ha (FAOSTAT,2021; Tripathi *et al*., 2022). Despite that India's current lentil production is inconsistent and lower in comparison to that of the other countries and the nation is yet to attain self-sufficiency in

lentil production. The reason for poor yield in the present lentil cultivars may be due to the cause of extreme weather events which lead to the outbreak of various biotic and abiotic stresses during the cropping seasons. At present one of the devasting biotic stress causing pathogen *Stemphylium botryosum* which cause Stemphylium blight in lentil, seems to be the biggest challenge to all the major lentil producers (Alam *et al*., 2019). The pathogen damages the foliar parts and results in severe yield loss for the crop (Sharma and Joshi, 2021). The homozygous

and homogenous genetic structure of lentil and the narrow genetic base of the existing varieties still worsens the situation (Tripathi *et al*., 2022). Hence, to mitigate the risks of disease outbreak, breeding for high yielding and disease tolerant lentil cultivars is highly essential. The efficient use of relevant traits which are associated with disease resistance in the varietal development program is an effective method to enhance cultivar productivity during the stress conditions. Therefore, the aim of the present study was to assess the genetic correlation among the quantitative yield attributing traits and disease incidence. Area Under Disease Progress Curve (AUDPC) was used to measure the extent of disease incidence after Simko and Piepho (2012). PCA helps in data transformation and reduction and is used as a criterion for plant selection (Sasipriya *et al*., 2022). Principal Component Analysis (PCA) derived biplot, a multivariate statistical analysis technique was thus used to visualize and elucidate the experimental results.

Lentil germplasm collection: Seeds of 50 lentil accessions were collected for the experiment from National Bureau of Plant Genetic Resources, New Delhi and International Centre for Agricultural Research in Dryland Areas, Bhopal, Madhya Pradesh. The collection includes four checks *viz*., IPL 220, IPL 406, L-4147 and WBL 77 of which the variety IPL 220, developed by Indian Institute of Pulse Research (ICAR-IIPR), Kanpur is resistant to Stemphylium blight disease and the remaining check varieties *viz*., IPL 406, L-4147 and WBL 77 are susceptible to the disease.

Experimental site: The experiment was performed in an Alpha-Lattice design with two replications at the instructional farm of Uttar Banga Krishi Vishwavidyalaya, Pundibari (NL 26°24'1" and EL 89°23'8") during *Rabi* 2021. Seeds of each genotype was sown in a unit plot

size of 2 m × 1.5 m in three rows with the spacing of 30 cm distance between the rows. Channel distance of 0.5 m was maintained. Irrigation was given at early flowering stage, a critical period for moisture stress during the crop growth. All other standard cultural operations were followed during the crop growth excluding disease control measures.

Morphological data: Observation were taken for a set of 20 quantitative morphological traits viz., days to 50% flowering (days), plant height (cm), primary branches/ plant (nos), secondary branches/ plant (nos), nodes/ plant (nos), leaflet number (nos), leaflet length (cm), leaf length (cm), tendril length (cm), peduncle length (cm), 100 - seeds weight (g), seed width (mm), seed thickness (mm), seeds/ pod (nos), pod/ cluster (nos), pods/ plant (nos), days to maturity (days), pod yield (g), harvest index and seed yield/ plant (g) by following the methods as per the minimal descriptor for the crop.

Assessment of Stemphylium blight disease: Hashemi's 0 – 10 scale for disease severity index was followed to record the disease scores (Hashemi *et al*., 2005) through visual observation of the disease symptoms in the field (**Table 1**). A total of eight disease scores were recorded at three days interval in all the 50 lentil genotypes over replications. The score data was further used to calculate Area Under Disease Progress Curve (AUDPC), a quantitative measure of disease incidence (Simko and Piepho, 2012).

$$\text{AUPDC} = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2} \right) (t_{i+1} - t_i) \ \ (\% \ \text{days}^{-1})$$

Where, y_i = disease score at the ith observation; n = total number of observations

Table 1. Stemphylium disease score chart (Hashemi *et al*., 2005)

Score	Symptoms	DR
0	No symptom	R
1	Dull leaves / few tiny tan spots	R
2	A few small to large chlorotic spots	MR
3	Expanding lesions on leaves and leaf drop starting	MR
4	20% nodes on main stem showing necrotic symptoms with leaf drop	MS
5	40% nodes on main stem showing necrotic symptoms with leaf drop	MS
6	60% nodes on main stem showing necrotic symptoms with leaf drop	S
7	80% nodes on main stem showing necrotic symptoms with leaf drop	S
8	100% leaves dried up/defoliated but small green tip recovering	HS
9	100% leaves dried up/defoliated including tip but stem still green	HS
10	Whole plant dies and completely dried up	HS

DR – Disease Reaction; R – Resistant; MR – Moderately Resistant; MS – Moderately Susceptible; S – Susceptible; HS – Highly Susceptible

AUDPC provides a linked measure of disease incidence and time as a single value (Schandry, 2017). Hence, it was used to summarize the disease severity in this study. The mean disease score and the average AUDPC derived from disease scores were presented in (**Table 2**).

Data Analysis: Analysis of variance (ANOVA), genotypic correlation and Principal Component Analysis (PCA) were done through the use of R Studio (R Core Team, 2022). The package 'variability' was used in genotypic correlation analysis (Popat *et al*., 2020). Biplot was constructed to display principal components results and correlogram was built with the help of 'corrplot' package to visualize correlation matrix (Taiyun Wei and Viliam Simko, 2021).

Analysis of variance: The ANOVA revealed that all the parameters considered in this study exhibited significant variation among the genotypes (**Table 3**). Thus, the parameters were further subjected for the assessment of correlation and principal component analysis.

Genotypic correlation: Significant genetic correlation was observed for AUDPC with days to 50% flowering, primary branches/ plant, 100 – seed weight and harvest index (**Table 4 and Fig. 1**). Among these AUDPC had a positive association with days to 50% flowering and primary branches whereas 100 – seed weight and harvest index were negatively correlated with the AUDPC. The positive correlation between AUDPC and days to 50 % flowering was in concordance with Kumar *et al*., 2022 in rice and Rahmatpour *et al*., 2021 in chickpea. The relationship found between disease progress and flowering time had shown that disease prevalence was influenced by the stage and duration of the crop. Razzak *et al*. (2018) have screened lentil germplasm against Stemphylium blight in three different stages and reported that the sensitivity of prevalence of Stemphylium mostly increased with age of plants and however at flowering stage most of the studied lentil lines were found to be resistant. The marked effect on level of Stemphylium blight disease incidence with respect to altered sowing dates in lentil was reported

Table 2. Mean disease score and AUDPC for 50 lentil genotypes

Genotype	MDS (score)	mAUDPC (% days^{-1})	DR	Genotype	MDS (score)	mAUDPC (% days^{-1})	DR
IC241067	4.5	64.50	MS	EC225486	4.5	51.75	MS
IC241090	5	60.75	MS	IC199779	3.5	41.25	MR
IC551597	6.5	74.25	S	IC78486	7	106.50	S
IC241119	3	57.75	MR	EC225484	5.5	83.25	MS
IC241072	1.5	25.50	R	EC223191	8	108.75	HS
IC565035	4.5	55.50	MS	IC241071	5.5	62.25	MS
IC614827	4	50.25	MS	IC78513	7	101.25	S
IC241082	5	57.00	MS	IC559415	6	61.50	S
IC78509	6	64.50	S	IC610426	6	65.25	S
IC78535	8	130.50	HS	IC241097	7	126.00	S
EC223226	7	85.50	S	IC241061	3.5	49.50	MR
IC78531	5	65.25	MS	IC620839	1	24.75	R
EC16391	6.5	78.00	S	IC544556	10	165.75	HS
IC78545	4.5	54.00	MS	IC614827	5	45.00	MS
EC223210	2.5	32.25	MR	IC201778	7	75.00	S
IC78540	6.5	80.25	S	EC223219	5.5	63.00	MS
EC223188	6	82.50	S	EC267544A	4.5	61.50	MS
IC78518	4.5	51.75	MS	EC267563	7	99.00	S
IC78547	6.5	80.25	S	EC267598	5	67.50	MS
WBL77(C)	4.5	58.50	MS	EC267604	5.5	62.25	MS
IC78454	6	78.00	S	EC267636	4.5	54.00	MS
IC78462	6	66.00	S	EC267657	5	75.75	MS
EC33920	3.5	56.25	MR	EC78408	5.5	64.50	MS
EC223244	6.5	71.25	S	L-4147(C)	4.5	52.50	MS
IPL406(C)	4	50.25	MS	IPL220(C)	2	33.75	MR

MDS – Mean disease score; mAUDPC – Mean area under disease progress curve; DR – Disease reaction; R – Resistant; MR – Moderately resistant; MS – Moderately susceptible; S – Susceptible; HS – Highly susceptible.

Table 3. Analysis of variance for 21 quantitative parameters in lentil

Sources	Genotype	Replication	Rep x Block	Residuals
Degrees of freedom	**49**	**1**	**8**	**41**
Traits	**Mean Sum of Squares**			
Days to50% flowering (Days)	92.46**	4.410	12.01	14.44
Plant height (cm)	55.74**	0.240	0.770	0.320
Primary branches/ plant (Nos)	0.851**	0.020	0.010	0.013
Secondary branches/ plant (Nos)	22.00**	0.041	0.065	0.144
Nodes per plant (Nos)	20.09**	0.156	0.160	0.241
Leaflets number (Nos)	2.103**	0.000	0.000	0.000
Leaflet length (cm)	0.090**	0.000	0.000	0.001
Leaf length (cm)	0.827**	0.017	0.027	0.026
Tendril length (cm)	2.369**	0.014	0.004	0.002
Peduncle length (cm)	0.415**	0.013	0.003	0.002
100 – seed weight (g)	0.299**	0.000	0.001	0.003
Seed width (mm)	0.275**	0.034	0.027	0.042
Seed thickness (mm)	0.150**	0.010	0.017	0.016
Seeds/pods (Nos)	0.166*	1.323	0.100	0.098
Pods/ clusters (Nos)	0.388**	0.000	0.044	0.034
Pods/ plants (Nos)	7947**	4156	967.0	608.0
Days to maturity (Days)	35.74**	31.36	26.64	14.31
Pod yield/ plant (g)	29.08**	1.486	2.027	1.170
Harvest Index (Index)	0.032**	0.000	0.006	0.007
Seed yield/ plant (g)	7.925**	0.630	2.202	0.640
AUDPC (% Days^{-1})	9612**	1063	1957	2364

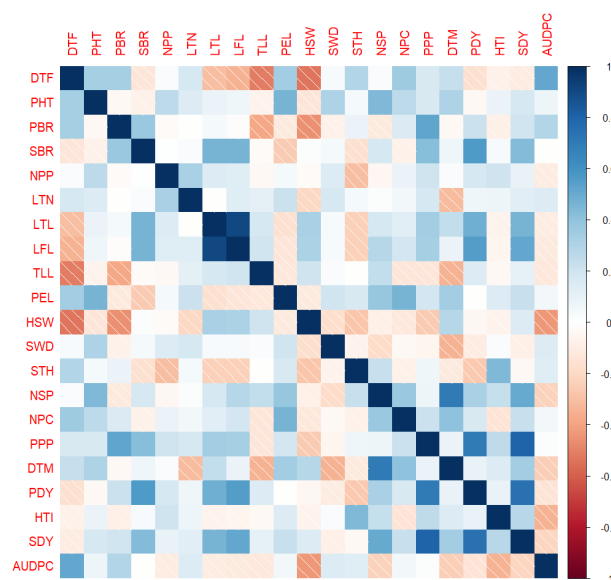*Significance P=0.05, **Significance P=0.01

Fig. 1. Genotypic correlogram of 21 quantitative parameters in lentil genotypes

DTF – Days to 50% flowering; PHT – Plant height; PBR – Primary branches per plant; SBR – Secondary branches per plant; NPP – Nodes per plant; LTN – Leaflets number; LTL – Leaflet length; LFL – Leaf length; TLL – Tendril length; PEL – Peduncle length; HSW – 100 seed weight; SWD – Seed width; STH – Seed thickness; NSP – Number of seeds per pod; NPC -Number of pods per cluster; PPP – Number of pod per plant; DTM – Days to maturity; PDY – Pod yield; HTI – Harvest index; SDY – Seed yield per plant; AUDPC – Area Under Disease Progress Curve

Table 4. Genotypic correlation among 21 quantitative parameters observed in lentil genotypes

	DTF	PHT	PBR	SBR	NPP	LTN	LTL	LFL	TLL	PEL	HSW	SWD	STH	NSP	NPC	PPP	DTM	PDY	HTI	SDY	AUDPC
DTF	1 **	0.33*	0.33*	-0.13	0.02	0.17	-0.30*	-0.34*	-0.51**	0.34*	-0.53**	0.03	0.29*	0.02	0.35*	0.16	0.23	-0.16	-0.08	-0.10	0.51**
PHT		1 **	-0.03	-0.07	0.26	0.14	0.08	0.06	-0.06	0.46**	-0.14	0.30*	0.04	0.44**	0.26	0.16	0.30*	-0.03	0.08	0.17	0.07
PBR			1 **	0.37**	-0.02	-0.008	0.04	-0.01	-0.38**	-0.11	-0.45**	-0.07	0.08	-0.11	0.15	0.52**	-0.03	0.21	-0.08	0.19	0.29*
SBR				1 **	0.005	0.02	0.46**	0.46**	-0.02	-0.25	0.01	0.04	-0.16	0.17	-0.07	0.42**	0.06	0.56**	0.03	0.43**	-0.001
NPP					1 **	0.32*	0.14	0.13	-0.03	0.03	-0.02	0.14	-0.30*	-0.04	0.08	0.20	0.02	0.17	0.20	0.09	-0.10
LTN						1 **	-0.003	0.13	0.11	0.20	-0.20	0.17	0.03	0.01	0.05	0.16	-0.31*	0.06	0.07	0.12	0.14
LTL							1 **	0.90**	0.17	-0.16	0.32*	0.03	-0.23	0.17	0.12	0.34*	0.24	0.48**	-0.06	0.46**	-0.10
LFL								1 **	0.19	-0.13	0.31*	0.03	-0.23	0.28*	0.18	0.33*	0.08	0.55**	-0.05	0.51**	-0.11
TLL									1 **	-0.12	0.20	0.02	-0.008	0.24	-0.13	-0.13	-0.34*	0.14	-0.03	0.10	-0.12
PEL										1 **	-0.11	0.19	0.16	0.38**	0.46**	0.18	0.34*	-0.00	0.14	0.22	0.05
HSW											1 **	-0.17	-0.27	-0.08	-0.12	-0.25	0.27*	-0.05	-0.06	0.14	-0.43**
SWD												1 **	-0.06	-0.18	-0.03	-0.05	-0.34*	-0.10	0.02	-0.08	0.14
STH													1 **	0.22	-0.07	0.06	-0.11	-0.26	0.44**	-0.03	0.13
NSP														1 **	0.37**	0.07	0.70**	0.32*	0.23	0.50**	-0.22
NPC															1 **	0.21	0.40**	0.16	-0.14	0.22	0.05
PPP																1 **	0.08	0.70**	0.25	0.80**	0.01
DTM																	1 **	0.09	0.14	0.34*	-0.24
PDY																		1 **	0.09	0.74**	-0.14
HTI																			1 **	0.27	-0.34*
SDY																				1 **	-0.22
AUDPC																					1 **

*Significance P=0.05, **Significance P=0.01. DTF – Days to 50% flowering; PHT – Plant height; PBR – Primary branches per plant; SBR – Secondary branches per plant; NPP – Nodes per plant; LTN – Leaflets number; LTL – Leaflet length; LFL – Leaf length; TLL – Tendril length; PEL – Peduncle length; HSW – 100 seed weight; SWD – Seed width; STH – Seed thickness; NSP – Number of seed per pod; NPC -Number of pod per cluster; PPP – Number of pod per plant; DTM – Days to maturity; PDY – Pod yield; HTI – Harvest index; SDY – Seed yield

by Huq and Khan (2007). The positive association of disease progress with primary branches may be due to the fact that increase in the number of branches increase the foliage density. And dense foliage favors increased leaf wetness period which support disease development in the crop. Significant increase in Stemphylium disease severity with increased leaf wetness duration in lentil was similarly observed by Mwakutuya and Banniza (2010). The negative impact of Stemphylium blight infection over seed yield in this experiment agree with the results of Hosen et al. (2009) and Subedi et al. (2021). It is said that the reduced seed yields due to the infection are caused by increased number of immature, deformed, wrinkled and stained seeds (Subedi et al., 2021). The economic trait seed yield/ plant showed significant positive relationship with seven quantitative traits viz., secondary branches/ plant, leaflet length, leaf length, number of seeds/ pods, number of pods/ plants, days to maturity and

pod yield/ plant. These results were in concordance with Erskine and Goodrich (1991); Sharma et al. (2022) and Hussain et al. (2022) in lentil.

Principal Component Analysis: Among the estimated 21 principal components first seven principal components were found to have the eigen value greater than unity **(Table 5)**. This indicated that the first seven principal components would play a significant role in classification of genotypes based on the variability present among them (Bhatti et al., 2022). The highest proportion of variance was recorded for principal component 1 (PC1) with 19.49 % variance followed by PC2 with 15.22% variance **(Table 5)**. From PC1, it is clear that 14 traits viz., seed yield/ plant, pod yield/ plant, leaf length, leaflet length, number of pods/ plants, secondary branches/ plant, days to maturity, number of seeds/ pod, AUDPC, number of nodes/ plant, days to 50% flowering, seed thickness, number of pods/

Table 5. Principal component analysis for 21 quantitative parameters in lentil

Parameter	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16	PC17	PC18	PC19	PC20	PC21
DTF	0.11	-0.45	0.04	-0.03	0.16	0.00	0.05	-0.23	0.08	-0.14	0.06	-0.18	0.21	-0.32	0.09	0.37	0.17	0.45	0.32	-0.08	0.00
PHT	-0.07	-0.27	-0.26	0.29	0.07	-0.03	0.30	0.01	-0.08	0.11	0.45	0.49	-0.21	-0.25	-0.11	0.13	-0.19	-0.02	-0.19	0.02	0.05
PBR	-0.09	-0.27	0.41	-0.21	0.04	0.07	0.05	0.04	-0.05	0.20	-0.05	0.41	0.19	0.44	0.06	-0.15	-0.10	0.43	-0.17	-0.05	0.07
SBR	-0.31	0.02	0.29	-0.10	-0.04	-0.03	0.30	-0.05	-0.18	-0.24	-0.26	0.16	0.17	-0.22	-0.62	-0.02	0.00	-0.17	0.20	-0.06	0.02
NPP	-0.12	-0.06	-0.05	0.37	-0.06	0.57	-0.04	-0.33	-0.05	0.27	0.17	-0.16	0.18	0.18	-0.24	-0.15	0.36	-0.06	0.00	-0.03	0.05
LTN	-0.05	-0.15	0.03	0.40	-0.28	0.00	-0.26	-0.41	0.20	-0.35	-0.38	0.27	0.06	-0.02	0.17	0.01	-0.21	-0.06	-0.14	0.14	-0.04
LTL	-0.37	0.14	0.08	0.13	0.17	-0.16	0.23	-0.11	0.29	0.20	0.06	-0.08	-0.01	-0.01	0.15	-0.21	-0.10	0.11	0.35	0.59	0.05
LFL	-0.38	0.14	0.06	0.18	0.12	-0.20	0.12	-0.13	0.26	0.18	-0.15	-0.08	-0.21	-0.07	0.14	-0.06	0.05	0.10	-0.09	-0.70	0.01
TLL	-0.07	0.27	-0.10	0.20	-0.27	-0.40	-0.24	-0.04	-0.25	0.10	0.31	-0.02	0.52	0.04	-0.08	0.02	-0.22	0.18	0.14	-0.15	-0.01
PEL	-0.02	-0.32	-0.35	0.16	0.05	-0.10	-0.17	0.34	0.10	-0.27	-0.06	-0.04	-0.11	0.10	-0.25	-0.56	0.05	0.24	0.19	-0.08	0.04
HSW	-0.09	0.37	-0.23	-0.03	0.22	0.07	0.04	0.01	0.35	-0.32	0.09	0.12	0.09	0.28	-0.28	0.32	0.14	0.29	-0.21	0.08	-0.25
SWD	0.03	-0.08	0.02	0.44	-0.12	-0.02	0.51	0.46	-0.10	-0.07	-0.22	-0.19	0.28	0.13	0.22	0.14	0.11	-0.01	-0.13	0.04	-0.08
STH	0.11	-0.18	-0.10	-0.26	-0.37	-0.32	0.13	-0.06	0.47	0.20	0.05	0.03	0.26	-0.14	-0.12	-0.14	0.36	-0.14	-0.27	0.07	0.02
NSP	-0.18	-0.09	-0.37	-0.14	-0.08	-0.27	0.12	-0.31	-0.48	0.09	-0.23	0.07	-0.20	0.23	0.10	0.04	0.32	0.06	0.05	0.10	-0.31
NPC	-0.11	-0.25	-0.12	0.11	0.36	-0.14	-0.37	0.19	0.07	0.44	-0.35	-0.04	0.14	0.04	-0.25	0.34	-0.10	-0.20	-0.06	0.10	-0.01
PPP	-0.35	-0.25	0.15	-0.10	-0.17	0.13	-0.15	0.21	0.14	-0.07	0.29	0.01	0.02	0.06	0.14	0.05	-0.04	-0.26	0.20	-0.09	-0.65
DTM	-0.13	-0.13	-0.32	-0.26	0.37	0.10	0.19	-0.22	-0.05	-0.18	0.02	-0.17	0.43	0.01	0.19	-0.24	-0.33	-0.23	-0.23	-0.09	0.00
PDY	-0.40	-0.02	0.13	-0.03	-0.06	0.03	-0.23	0.12	-0.23	-0.08	0.06	-0.29	-0.07	-0.38	-0.01	-0.07	0.08	0.29	-0.55	0.24	-0.02
HTI	-0.10	-0.07	-0.27	-0.19	-0.48	0.25	0.18	0.00	0.12	0.17	-0.15	-0.28	-0.17	0.09	-0.18	0.19	-0.49	0.22	0.04	-0.02	0.06
SDY	-0.42	-0.10	-0.11	-0.13	-0.12	-0.03	-0.11	0.12	0.01	-0.25	0.15	0.03	0.00	0.25	0.18	0.28	0.21	-0.20	0.10	-0.02	0.63
AUDPC	0.13	-0.25	0.30	0.13	0.07	-0.36	0.08	-0.24	0.00	-0.16	0.26	-0.42	-0.23	0.39	-0.26	0.06	-0.14	-0.13	-0.18	0.04	0.00
EV	**4.09**	**3.20**	**2.30**	**1.85**	**1.69**	**1.26**	**1.04**	0.87	0.83	0.66	0.62	0.50	0.42	0.39	0.35	0.29	0.25	0.17	0.15	0.06	0.02
SD	2.02	1.79	1.52	1.36	1.30	1.12	1.02	0.93	0.91	0.81	0.79	0.71	0.65	0.63	0.59	0.54	0.50	0.41	0.39	0.24	0.13
PV	0.19	0.15	0.11	0.09	0.08	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00
CuV	0.19	0.35	0.46	0.54	0.63	0.69	0.73	0.78	0.82	0.85	0.88	0.90	0.92	0.94	0.96	0.97	0.98	0.99	1.00	1.00	1.00

DTF – Days to 50% flowering; PHT – Plant height; PBR – Primary branches per plant; SBR – Secondary branches per plant; NPP – Nodes per plant; LTN – Leaflets number; LTL – Leaflet length; LFL – Leaf length; TLL – Tendril length; PEL – Peduncle length; HSW – 100 seed weight; SWD – Seed width; STH – Seed thickness; NSP – Number of seeds per pod; NPC -Number of pods per cluster; PPP – Number of pod per plant; DTM – Days to maturity; PDY – Pod yield; HTI – Harvest index; SDY – Seed yield per plant; AUDPC – Area Under Disease Progress Curve; EV – Eigen value; SD – Standard deviation; PV – Proportion of variation; CuV – Cumulative proportion of variance.
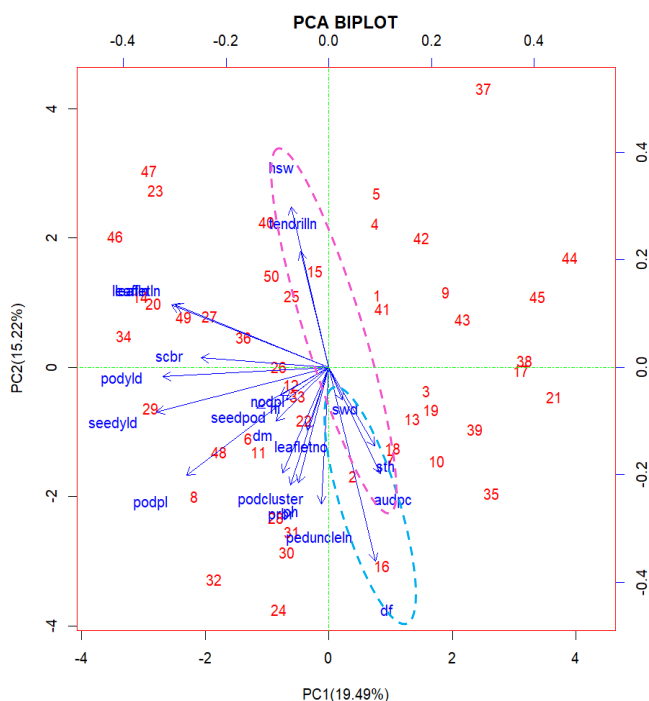
Fig. 2. PCA biplot for Principal Component 1 (PC1) and Principal Component 2 (PC2)

cluster and harvest index were the significant contributors towards variability among the studied genotypes **(Table 5)**. Thus, these traits should be given more importance during the crop improvement program in the studied set of genotypes. Debnath *et al.* (2022) have also reported grain yield, days to 50 % flowering and harvest index with largest PC1 loadings in their study on mutagen treated lentil populations.

Biplot analysis: Since the first two components PC1 and PC2 explained the greatest variation in the population, they were taken to construct the biplot **(Fig. 2)**. In a biplot, the original variables i.e., traits studied, were shown as vectors from the origin. If the direction of the vector is more parallel to the principal component axis, the more it contributes only to that principal component (Hartmann *et al.*, 2018). Here, the vectors of the traits seed yield and pod yield were observed to be more parallel with PC1 axis. Likewise, PC2 was highly influenced by the vectors of days to 50% flowering and 100 – seed weight. The length of the vector on the other is directly proportional to the range of variability (Hartmann *et al.*, 2018). The traits *viz.*, days to 50% flowering, pod yield and seed yield noticed with the longest vector length in the biplot explained the highest contribution for variability compared to the other traits. The closer angle between the vectors of AUDPC and days to 50% flowering revealed that these parameters were positively correlated with each other (blue ellipse) (Jolliffe and Cadima, 2016). The negative correlation between AUDPC and 100 – seed weight was marked with opposite vector angles (pink ellipse) in the biplot **(Fig. 2)**.

Thus, it is obvious that PCA has simplified the identification of traits with high magnitude of variation contribution when considering several traits simultaneously. PCA have shown that most of the variation among the tested lentil genotypes was attributed by seed yield/ plant and pod yield/plant. Further, it was depicted from the corrplot and PCA biplot that Stemphylium disease progress was more correlated with days to 50% flowering and 100 – seed weight. Therefore, association and selection of traits based on PCA would ease the crop improvement program in case of complex trait system.

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