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MULTIVARIATE AND ASSOCIATION ANALYSIS OF YIELD-CONTRIBUTING TRAITS IN GROUNDNUT (*Arachis hypogaea* L.)

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ABSTRACT

Analysis of variance showed significant differences among fifteen groundnut genotypes for ten evaluated traits in a randomised complete block design during *Kharif* 2024. Dry pod yield exhibited moderate variability, heritability and genetic advance, indicating good potential for selection-based improvement. Days to first flowering, days to 50% flowering, initial plant stand, shelling percentage, SMK% and dry pod yield were positively associated with kernel yield, with dry pod yield exerting the highest direct effect, followed by shelling percentage. Principal component analysis explained 81.22% of the total variability through three components, with major contributions from dry pod yield, days to 50% flowering, kernel yield, and SMK%. Genotypes K 2682, K 2683, K 2685, K 2686, K 2684 and K 2687 showed superior performance and should be evaluated in multi-location trials to assess stability. Integrating phenotypic selection with multivariate analysis can enhance selection efficiency and support the development of high-yielding, stable groundnut varieties.

Keywords : Groundnut, Principal component analysis, variability, correlation, kernel yield

Introduction

Groundnut (*Arachis hypogaea* L.) is an annual legume valued for its seeds, which contain 22-30% digestible protein and 44-56% edible oil, rich in linoleic and oleic acids. It is cultivated in more than 100 countries, covering about 30.5 million hectares, with a global production of 54.2 million tonnes and an average productivity of 1.75–1.80 t/ha (FAOSTAT, 2025). In addition to its role as a major oilseed crop, groundnut also provides protein-rich fodder for livestock (Denwar *et al.*, 2021). Despite progress in varietal improvement, yield gains remain inconsistent across regions, highlighting the need for efficient exploitation of genetic variability (Motagi *et al.*, 2022).

Developing high-yielding hybrids remains challenging, underscoring the importance of identifying and assessing genetic variability for

effective selection in breeding programs. Efficient use of existing variability requires selecting promising genotypes with desirable traits from diverse materials. Assessing variability and genetic diversity within germplasm is critical for identifying superior genotypes. Genotypic and phenotypic coefficients of variation (GCV and PCV) are commonly estimated to evaluate trait variability. Heritability indicates the genetic contribution to phenotypic expression and the likelihood of trait transmission (Sravanti *et al.*, 2024). Combining heritability with genetic advance clarifies the gene action underlying specific traits.

Yield is a complex trait influenced by multiple attributes. Understanding relationships among yield and its components enables simultaneous selection for yield improvement. Correlation and path coefficient analyses facilitate the identification of key yield-

contributing characters and support effective selection strategies (Sukrutha *et al.*, 2025). In addition, principal component analysis (PCA) summarises data dimensionality and aids in assessing genetic diversity. Therefore, the present study aims on evaluating variability, trait associations and principal component analysis to identify superior genotypes based on yield performance and related traits.

Materials and Methods

The study was conducted at the Agricultural Research Station, Kadiri, located in the scarce rainfall zone of Andhra Pradesh (14°06' N, 78°10' E; 560 m above mean sea level), receiving an average annual rainfall of 550-600 mm. The experimental material comprised 15 early-generation breeding lines along with five check varieties (Kadiri 6, Kadiri 7, Kadiri 9, Kadiri Lepakshi and Visishta). The trial was laid out in a randomized block design with three replications, maintaining a spacing of 30 cm between rows and 10 cm between plants. Recommended agronomic practices were followed to ensure optimal crop growth.

Analysis of variance was performed to determine the significance of genotypic differences (Panse and Sukhatme, 1954). Genotypic and phenotypic variances were estimated using the formula proposed by Burton and Devane (1953). Variance and covariance components were computed as per Falconer and Mackay (1996) to derive phenotypic and genotypic correlation coefficients. Path coefficient analysis was carried out using the method of Dewey and Lu (1959). All statistical analyses were performed using R software.

Results and Discussion

Adequate genetic variation is fundamental for successful crop improvement (Narasimhulu *et al.*, 2012). The analysis of variance (ANOVA) (Table 1) revealed significant differences among genotypes for the evaluated traits, except initial and final plant stand, indicating the presence of substantial exploitable variation. The non-significant variation in plant stand reflects uniform crop establishment and survival across genotypes (Gonya *et al.*, 2018).

A wide range of variation was observed for key traits, such as 100-kernel weight (26g to 54g), sound mature kernel weight (24g to 51g), dry pod yield (2700 kg/ha to 5078 kg/ha) and kernel yield (1763 kg/ha to 3467 kg/ha), indicates significant genetic variability among genotypes (Table 2). The highest dry pod yield (Fig 1) was observed in K2682 (3652 kg/ha), followed by K2687 (3426 kg/ha) and K2683 (3194 kg/ha). This

variability is crucial for selecting superior genotypes with desirable trait combinations. The observed differences in yield and its components reflects both genetic and environmental influences, with substantial genetic variability available for effective selection. These results are in agreement with earlier findings (Sridevi *et al.*, 2022; Umadevi *et al.*, 2025).

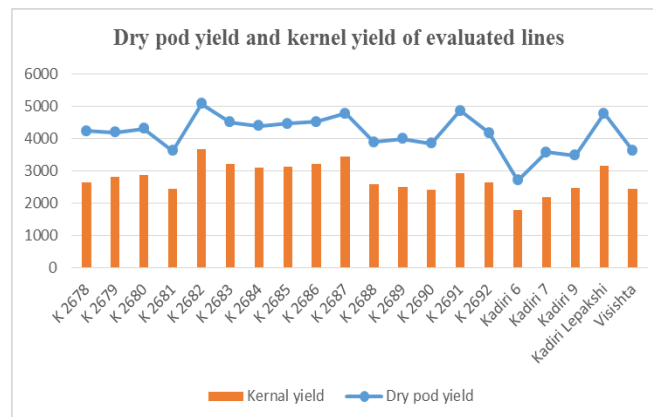


Fig. 1 : Mean dry pod yield and kernel yield of evaluated groundnut genotypes

Variability parameters like genotypic and phenotypic coefficients of variation (GCV and PCV), heritability, genetic advance and genetic advance as percent of the mean (GAM) are presented in Table 2. GCV ranged from 1.72 (days to first flowering) to 19.28 (sound mature kernel weight), while PCV ranged from 2.29 (days to 50% flowering) to 22.89 (sound mature kernel weight). Moderate GCV was observed for final plant stand (15.68), 100-kernel weight (18.43), sound mature kernel weight (19.28), dry pod yield (11.94) and kernel yield (15.15), whereas the remaining traits exhibited low variability. Initial and final plant stand showed low heritability (1.84, 2.83) and GAM (4.84, 5.43) despite wider ranges, indicating strong environmental influence and limited genetic control, making them unreliable for selection. Among traits with moderate variability, 100-kernel weight (71%, 32.15) and kernel yield (65%, 25.29) exhibited high heritability coupled with high GAM, suggesting predominant genetic control and good response to selection. High GAM reflects the potential for effective improvement through direct selection (Mubai *et al.*, 2019; Aparna *et al.*, 2018). These traits are reliable to design a selection criterion for yield enhancement in groundnut breeding. Dry pod yield showed moderate heritability and GAM (49%, 17.28), indicating environmental influence on its expression. Therefore, indirect selection through highly heritable traits, such as kernel yield and 100-kernel weight would be more effective for improving yield (Yadav *et al.*, 2023; Habibe, 2023).

Correlation among traits may result from pleiotropy, linkage or physiological associations. In this study, significant associations were observed among phenological, yield, and yield-related traits at both genotypic (G) and phenotypic (P) levels, with genotypic correlations generally higher than phenotypic ones, indicating strong inherent associations among traits with relatively less environmental influence, thereby explaining reliable selection relationships (Table 3). Strong positive correlations were recorded between shelling percentage and SMK% (0.99 and 0.99), followed by 100 kernel weight and SMK weight (0.98 and 0.98); dry pod yield and kernel yield (0.93 and 0.93), at both genotypic and phenotypic levels. These associations highlight the close linkage of kernel recovery and seed size traits with yield performance. The strong association between dry pod yield and kernel yield confirms that pod yield is a major determinant of final productivity (Wadikar *et al.*, 2018 and Reddy *et al.*, 2023). Shelling percentage showed significant positive correlations with SMK per cent (0.99 and 0.99), SMK weight (0.99 and 0.99) and kernel yield (0.69 and 0.41), emphasizing its role in improving kernel recovery and overall yield. Similar findings highlighting the importance of kernel-related traits in yield improvement have been reported by Gedifew, 2024, Yadav *et al.*, 2023 and Umadevi *et al.*, 2025. Dry pod yield exhibited a strong positive correlation with kernel yield (0.93 and 0.93), days to 1st flowering (0.55 and 0.47), days to 50% flowering (0.61 and 0.45) and initial plant stand (0.57 and 0.32), indicating the importance of optimum establishment and phenology. Similarly, kernel yield showed significant positive correlation with days to 1st flowering (0.59 and 0.49), days to 50% flowering (0.68 and 0.53), initial plant stand (0.66 and 0.42), shelling percentage (0.69 and 0.41), SMK% (0.70 and 0.42) and dry pod yield (0.93 and 0.93), reflecting its complex inheritance. Overall, traits such as shelling percentage, SMK%, plant stand and dry pod yield can serve as reliable selection criteria for improving kernel yield in groundnut.

Path coefficient analysis (Table 4) partitioned the direct and indirect effects of component traits on kernel yield, clarifying insight into their relative importance. At both genotypic and phenotypic levels, dry pod yield exerted the highest direct effects (0.8192 and 0.9023) on kernel yield, followed by shelling percentage (0.3442 and 0.3390). In contrast, negative direct effects were observed for initial plant stand (-0.05, -0.0012) at both genotypic and phenotypic levels suggesting that excessive plant density can reduce yield due to competition. The strong positive direct contribution of dry pod yield on kernel yield confirms its key role in

determining economic yield. Highest positive indirect effects of days to 1st flowering, days to 50% flowering and initial plant stand on kernel yield was observed through dry pod yield. Delayed flowering (for both the first and 50% occurrences) can enable plants to gather more biomass and build a more robust reproductive structure, which may improve dry pod yield. In the same way, having a good initial plant population guarantees an optimal number of plants, allowing for better use of resources like light, nutrients, and water, all of which contribute to higher pod yield. The significant indirect impact on dry pod yield emphasizes its importance as a key factor influencing overall yield. Several traits, such as SMK weight and 100-kernel weight, influenced yield indirectly through SMK% and shelling percentage. The greater magnitude of genotypic effects compared to phenotypic effects suggests these relationships are primarily genetic, with minimal environmental interference. These results align with recent studies highlighting the importance of SMK%, shelling percentage, and plant stand in yield determination (Gedifew, 2024; Yadav *et al.*, 2023; Umadevi *et al.*, 2025).

Principal component analysis (PCA) extracted ten principal components (PCs) from the mean dataset (Fig. 2) the first three PCs each with eigenvalues >1, together explained 81.22% of the total variance. The PC1 (41.63%) and PC2 (23.46%) together accounted for 65.10%, highlighting their major contribution to trait divergence (Table 5). The third through sixth PCs accounted for 16.1%, 7.3%, 6.6%, and 3.1% of the variance, respectively. Scrutiny of the scree plot suggests that retaining two to three PCs is sufficient for subsequent analysis, as they provide an appropriate balance between parsimony and variance retention, as additional PCs provide only marginal gains and are unlikely to capture meaningful structure.

PC1 was mainly associated with kernel yield, dry pod yield, days to 1st flowering, days to 50% flowering and 100-kernel weight, indicating these traits collectively influence productivity. PC2 was primarily driven by shelling percentage and SMK weight, emphasizing their importance for seed size and quality. These results are consistent with previous studies emphasizing pod and kernel traits as key contributors to genetic variability in groundnut (Hariharan *et al.*, 2026; Vishnuprabha *et al.*, 2024; Sukrutha *et al.*, 2023).

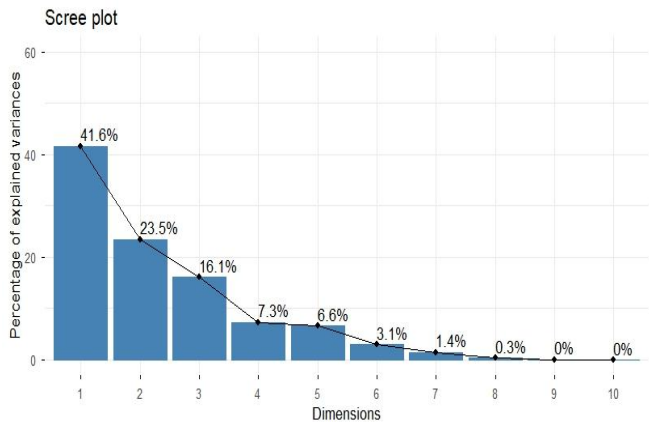


Fig. 2 : Contribution of percent variation by various principal components in groundnut

Traits such as kernel yield, dry pod yield, days to 50% flowering and SMK% were closely aligned on the positive side of PC1, suggesting that genotypes in this direction are high-yielding with desirable traits. Consistent with this pattern, previous studies by Mekonen (2022), Kohar *et al.* (2023) and Isler *et al.* (2023) reported positive associations of yield with 100-seed weight, plant height, and shelling percentage, highlighting their importance as key contributors to productivity. Days to first flowering and initial plant stand were grouped together, indicating their combined influence on crop establishment and subsequent yield (Fig. 3). 100-kernel weight and SMK weight were positively associated but a relatively weaker linkage with yield traits. Shelling percentage had a moderate, independent association, reflecting its specific role in kernel recovery. Genotypes K 2682, K 2683, K 2685, 2686, 2684 and K 2687 were positioned closer to yield-related traits, indicating higher productivity potential, which is also supported by their kernel and dry pod yield performance (Fig. 1). Kadiri Lepakshi, being closer to the origin, showed comparatively stable performance across traits. Overall, the biplot suggests that selection of genotypes associated with dry pod yield, kernel yield, days to 50% flowering, and SMK% would be effective for yield improvement in groundnut.

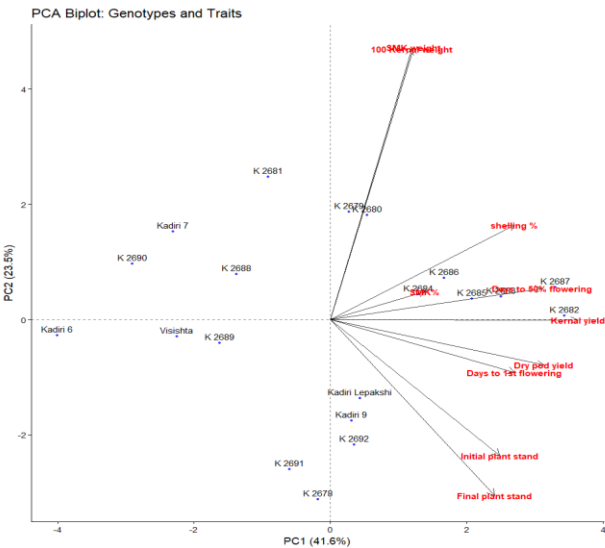


Fig. 3 : PCA biplot showing distribution of studied trait and genotypes

Conclusion

Gaining insights into the variability within a population is crucial for developing superior genotypes. The present study identified several important traits such as shelling percentage, SMK%, plant stand and dry pod yield as key traits for effective phenotypic selection aimed at yield improvement. Principal Component Analysis (PCA) also revealed that dry pod yield, days to 50% flowering, kernel yield and SMK% are major contributing to overall variability, highlighting their importance as selection criteria. Additionally, the genotypes K 2682, K 2683, K 2685, K 2686, K 2684, and K 2687 exhibited superior performance and should be evaluated in multi-location trials to assess yield stability. Promising lines with consistent performance can be advanced for release as commercial varieties. Integrating phenotypic selection with PCA enhances selection efficiency and accelerates genetic improvement. This approach also facilitates the development of stable and high-performing genotypes, contributing to sustainable groundnut production.

Table 1 : Analysis of variance (ANOVA) for ten studied traits in groundnut

	RMSS (df=2)	TMSS (df=19)	EMSS (df=38)
Days to 1 st flowering	0.32	0.86**	0.21
Days to 50% flowering	0.02	1.28**	0.17
Initial plant stand	606.95	345.99	206.39
Final plant stand	17541.35	15196.99	13976.61
Shelling percentage	2.36	41.40**	3.93
100 kernel weight	24.37	184.48**	21.48
SMK %	0.0002	0.004**	0.0004
Sound mature kernels weight	29.12	180.21**	21.68
Dry pod yield	757211.96	986892.12**	251240.47
Kernel yield	299900.91	623711.82**	92689.31

Table 2 : Estimates of variability parameters for the studied traits in groundnut

Trait	Mean	Range	GCV	PCV	h^2	GA	GAM
Days to 1 st flowering	27.0	26-28	1.72	2.42	50	0.68	2.52
Days to 50% flowering	32.1	31-33	1.88	2.29	67.7	1.02	3.19
Initial plant stand	124.0	97-136	5.48	12.78	1.84	6.02	4.84
Final plant stand	114.0	90-128	15.68	19.29	2.83	6.98	5.43
Shelling percentage	67.0	60-72	5.28	6.05	76	6.34	9.49
100 kernel weight	40.0	26-54	18.43	21.77	71	12.85	32.15
SMK%	89.8	85-93	3.92	4.42	77	0.06	7.09
Sound mature kernels weight	38.0	24-51	19.28	22.89	70	12.61	33.44
Dry pod yield	4147.0	2700-5078	11.94	16.99	49	716.93	17.28
Kernel yield	2775.0	1763-3467	15.15	18.71	65	702.13	25.29

GCV-Genotypic coefficient of variation, PCV-Phenotypic coefficient of variation, h^2 -heritability, GA-Genetic advance, GAM-Genetic advance as percent of mean

Table 3 : Genotypic and phenotypic correlation coefficients for the studied traits in groundnut

Trait		Days to 1 st flowering	Days to 50% flowering	Initial plant stand	Final plant stand	shelling %	100 Kernel weight	SMK %	SMK weight	Dry pod yield	Kernel yield	
Days to 1 st flowering	G	1										
	P	1										-0.1
Days to 50% flowering	G	0.79**	1									-0.2
	P	0.76**	1									-0.3
Initial plant stand	G	0.41	0.55*	1								-0.4
	P	0.15	0.16	1								-0.5
Final plant stand	G	0.18	-0.01	0.68**	1							-0.6
	P	0.22	0.17	0.23	1							-0.7
shelling %	G	0.43	0.52*	0.57**	0.85**	1						-0.8
	P	0.15	0.31*	0.37**	0.19	1						-0.9
100 Kernel weight	G	-0.04	0.35	-0.24	-0.49**	0.45**	1					1
	P	-0.07	0.17	0.091	-0.08	0.47**	1					0.9
SMK%	G	0.44	0.52*	0.57**	0.95**	0.99**	0.45**	1				0.8
	P	0.15	0.32*	0.37**	0.19	0.99**	0.47**	1				0.7
SMK weight	G	-0.04	0.32	-0.26	-0.41	0.48**	0.98**	0.48**	1			0.6
	P	-0.06	0.17	0.08	-0.08	0.48**	0.98**	0.48**	1			0.5
Dry pod yield	G	0.55*	0.61**	0.57**	-0.52**	0.4	0.09	0.41	0.11	1		0.4
	P	0.47**	0.45**	0.32*	-0.04	0.08	0.07	0.08	0.1	1		0.3
Kernel yield	G	0.59**	0.68**	0.66**	-0.52**	0.69**	0.26	0.70**	0.28	0.93**	1	0.2
	P	0.49**	0.53**	0.42**	0.02	0.41**	0.24	0.42**	0.26*	0.93**	1	0.1

Table 4 : Genotypic and phenotypic path coefficients for the studied traits in groundnut

		Days to 1 st flowering	Days to 50% flowering	Initial plant stand	Final plant stand	shelling %	100 Kernel weight	SMK %	SMK weight	Dry pod yield
Days to 1st flowering	G	-0.0454	0.0664	-0.0221	0.0036	0.1505	0.0114	-0.008	-0.0106	0.4544
	P	0.0063	0.0093	-0.0002	-0.0017	0.0511	-0.0024	0.0001	0.0017	0.4320
Days to 50% flowering	G	-0.0360	0.0839	-0.0292	-0.0003	0.1797	-0.0944	-0.008	0.0876	0.5029
	P	0.0048	0.0121	-0.0002	-0.0013	0.1076	0.0056	0.0005	-0.0042	0.4083
Initial plant stand	G	-0.0190	0.0464	-0.0528	0.0248	0.1966	0.0662	0.003	-0.0698	0.4699
	P	0.0010	0.0020	-0.0012	-0.0018	0.1276	0.0030	0.0002	-0.0019	0.2955
Final plant stand	G	-0.0085	-0.0012	-0.0678	0.0194	0.3581	0.2965	0.015	-0.2952	-0.839
	P	0.0014	0.0021	-0.0003	-0.0076	0.0666	-0.0028	0.0001	0.0019	-0.039
shelling %	G	-0.0199	0.0438	-0.0302	0.0201	0.3442	-0.1218	-0.003	0.1299	0.3342
	P	0.0009	0.0038	-0.0005	-0.0015	0.3390	0.0154	0.002	-0.0117	0.0723
100 Kernel weight	G	0.0020	0.0299	0.0132	-0.0217	0.1582	-0.2650	0.0027	0.2657	0.0774
	P	-0.0005	0.0021	-0.0001	0.0007	0.1602	0.0326	0.00	-0.0238	0.0700

SMK%	G	0.0723	0.1278	0.03299	-0.055	0.1966	-0.1335	0.0054	-0.1596	0.607
	P	0.07	0.09	0.008	0.03	0.056	0.0052	0.01	0.00447	0.07
SMK weight	G	0.0018	0.0277	0.0139	-0.0215	0.1683	-0.2650	0.0032	0.2656	0.0959
	P	-0.0004	0.0021	-0.0001	0.0006	0.1648	0.0321	0.001	-0.0242	0.0904
Dry pod yield	G	-0.0252	0.0515	-0.0303	-0.0198	0.1404	-0.0250	-0.004	0.0311	0.8192
	P	0.0030	0.0055	-0.0004	0.0003	0.0272	0.0025	-0.002	-0.0024	0.9023

Table 5: Estimates of eigen values, variance percent and factor loadings for three principal components

Variables	PC1	PC2	PC3
Days to first flowering	0.69	-0.18	0.49
Days to 50% flowering	0.79	0.10	0.31
Initial plant stand	0.63	-0.45	-0.57
Final plant stand	0.61	-0.58	-0.48
Shelling percentage	0.35	0.09	0.71
100 kernel weight	0.69	0.31	-0.25
SMK %	0.30	0.90	-0.25
Sound mature kernels weight	0.31	0.91	-0.25
Dry pod yield	0.80	-0.15	0.15
Kernel yield	0.93	0.00	0.04
Eigen value	4.16	2.34	1.61
Variance percent	41.63	23.46	16.12
Cumulative variance percent	41.63	65.10	81.22

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