International Journal of Agriculture and Plant Science
www.agriculturejournal.in
Online ISSN: 2664-7664
Received: 12-06-2026, Accepted: 12-07-2026, Published: 27-07-2026
Volume 8, Issue 3, 2026, Page No. 187-196

Correlation and path analysis for root traits, phosphorus use efficiency, yield and quality traits in groundnut (*Arachis hypogaeae* L.)

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DOI: https://doi.org/10.66856/ijaps.2026.8.3.8181

Abstract
Groundnut (*Arachis hypogaea* L.) is an important oilseed crop cultivated worldwide for its edible oil, protein-rich kernels and soil fertility improvement through biological nitrogen fixation. Genetic variability, correlation and path coefficient analyses were carried out for twenty-two physiological, root, phosphorus use efficiency, yield and quality traits in twenty advanced breeding lines along with four check varieties of groundnut. Considering the mean performance, the genotypes TCGS-2638, TCGS-2572, TCGS-2634 and TCGS-2635 registered superiority for important yield and associated traits *viz*., number of mature pods plant^{-1}, hundred pod weight (g), hundred kernel weight (g), pod yield plant^{-1} (g), kernel yield plant^{-1} (g), phosphorus uptake (kg ha^{-1}), harvest index (%) and shelling per cent (%). High percentage of PCV, GCV, heritability coupled with high genetic advance as per cent of mean were recorded for phosphorus uptake (Kg ha^{-1}), phosphorus content (%), root dry weight (g), root: shoot ratio, leaf acid phosphatase activity (µ mol g^{-1} FW h^{-1}), kernel yield plant^{-1} (g) and pod yield plant^{-1} (g), indicating the predominance of additive gene action and effectiveness of selection for these traits. Correlation analysis revealed that the traits kernel yield plant^{-1} (g), number of mature pods plant^{-1}, hundred pod weight (g), hundred kernel weight (g), harvest index (%) and phosphorus uptake (kg ha^{-1}) were positively associated with pod yield plant^{-1} (g). Inter-correlation among these traits also recorded significant positive association, indicating their importance in yield improvement. Therefore, these characters can be considered as important yield attributing traits and due importance should be given while breeding for high pod yield plant^{-1} (g) in groundnut. Moreover, path coefficient analysis revealed that kernel yield plant^{-1} (g) exerted the highest positive direct effect on pod yield plant^{-1} (g), while harvest index (%) also recorded high positive direct effects. The traits *viz*., number of mature pods plant^{-1}, hundred pod weight (g), hundred kernel weight (g), shelling per cent (%), phosphorus uptake (kg ha^{-1}) and phosphorus content (%) exhibited moderate to high indirect effects through kernel yield plant^{-1} (g) and harvest index (%) on pod yield plant^{-1} (g). Hence, greater emphasis should be placed on these traits for yield improvement and enhancement of phosphorus use efficiency in groundnut.

Keywords: Correlation, genetic variability, heritability, path analysis, phosphorus use efficiency, Groundnut

Introduction

Groundnut (*Arachis hypogaea* L.) is one of the most important legume and oilseed crops cultivated throughout the tropical and subtropical regions of the world. It serves as a major source of edible oil, high-quality protein and dietary energy, while also contributing to soil fertility through biological nitrogen fixation. Owing to its nutritional, economic and industrial importance, groundnut occupies a prominent position among oilseed crops. However, productivity of groundnut is often constrained by poor soil fertility, particularly phosphorus deficiency, which adversely affects root growth, nutrient acquisition and yield. Therefore, improving yield potential and phosphorus use efficiency has become an important objective in modern groundnut breeding programmes (Janila *et al*., 2013; Pandey *et al*., 2020) [11, 25].

Genetic variability forms the basis of crop improvement and provides opportunities for the selection of superior genotypes. Knowledge of the magnitude and nature of variability present in breeding materials is essential for the effective improvement of economically important traits. Estimates of phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability and genetic advance provide valuable information regarding the genetic architecture of traits and the effectiveness of selection. Traits governed predominantly by additive gene action can be improved effectively through direct selection, whereas traits influenced by non-additive gene action require alternative breeding approaches.

Pod yield in groundnut is a complex quantitative trait controlled by several interrelated physiological, root, phosphorus use efficiency, yield and quality attributes (Dhillon *et al*., 1992; Singh *et al*., 2004) [6, 34]. In any plant breeding programme, it is essential to understand the association among yield and yield-related traits for effective selection. Selection based on highly heritable and simply inherited component traits is often more reliable and efficient than direct selection for yield itself. Therefore, understanding the nature and extent of association among root traits, phosphorus use efficiency traits, yield attributes and quality traits, as well as their inter-relationships with pod yield, is an essential prerequisite for formulating effective breeding strategies for yield improvement in groundnut.

Correlation analysis provides information on the degree and direction of association among characters, while path coefficient analysis partitions the correlation into direct and indirect effects, thereby identifying traits that contribute most effectively to yield improvement. Such information facilitates the development of reliable selection criteria for enhancing productivity and nutrient use efficiency in groundnut (Dewey and Lu, 1959) [5]. Therefore, the present investigation was undertaken to study the genetic variability, character association and path coefficient analysis for physiological traits, root traits, phosphorus use efficiency traits, yield attributes and quality traits in advanced breeding lines of groundnut, with the objective of identifying superior genotypes and key traits for effective yield improvement.

Material and methods

The present investigation was carried out during *kharif* 2025 at the Dryland Farm, Agricultural College, Tirupati. The experimental material comprised twenty advanced breeding lines of groundnut along with four check varieties, which were evaluated in a Randomized Block Design (RBD) with two replications. Each genotype was sown in three rows of 4 m length with a spacing of 30 cm between rows and 10 cm between plants. The field was prepared to a fine tilth and farmyard manure (FYM) @ 10 t ha^{-1} was incorporated during land preparation. Seeds were treated with Dithane M-45 @ 3 g kg^{-1} before sowing. The crop was raised under rainfed conditions with lifesaving irrigation provided through sprinkler irrigation whenever necessary. A recommended fertilizer dose of 20 kg N, 40 kg P_2O_5 and 50 kg K_2O ha^{-1} was applied through urea, single super phosphate and muriate of potash, respectively, along with gypsum @ 500 kg ha^{-1} at first flowering. Standard agronomic and plant protection measures were followed throughout the crop growth period to ensure a healthy crop stand.

Observations Recorded

Observations were recorded and analysed on twenty-two characters *viz*., days to 50% flowering, days to maturity, number of primary branches $plant^{-1}$, number of mature pods $plant^{-1}$, hundred pod weight (g), hundred kernel weight (g), sound mature kernel (%), shelling (%), dry haulms yield $plant^{-1}$ (g), pod yield $plant^{-1}$ (g), kernel yield $plant^{-1}$ (g), harvest index (%), protein content (%), oil content (%), root length (cm), shoot length (cm), root dry weight (g), shoot dry weight (g), root: shoot ratio, phosphorus content (%), phosphorus uptake (kg ha^{-1}) and leaf acid phosphatase activity (µmol p-NP g^{-1} FW h^{-1}). The observations were recorded on five randomly selected competitive plants in each genotype in each replication, except days to 50% flowering and days to maturity, which were recorded on plot basis.

Results and Discussion

Mean Performance

In a breeding programme, mean performance is the foremost important criterion for selecting superior genotypes. Considerable variation was observed among the twenty advanced breeding lines and four check varieties for all the twenty-two characters studied, indicating the presence of substantial variability among the genotypes (Table 1).

Among the evaluated genotypes, TCGS-2572 recorded superiority for number of mature pods $plant^{-1}$ (24.00), harvest index (48.86%) and protein content (26.76%). TCGS-2634 exhibited higher mean values for hundred pod weight (110.43 g), hundred kernel weight (56.00 g), kernel yield $plant^{-1}$ (18.35 g) and pod yield $plant^{-1}$ (24.47 g). The genotype TCGS-2638 recorded superior performance for shoot length (50.18 cm), root length (10.15 cm), dry haulms yield $plant^{-1}$ (35.72 g), phosphorus uptake (1.68 kg ha^{-1}) and oil content (50.36%). TCGS-2641 recorded the highest shoot dry weight (26.50 g), while TCGS-2632 possessed the highest root dry weight (11.61 g) and sound mature kernel percentage (98.00%). TCGS-2561 exhibited the highest number of primary branches $plant^{-1}$ (7.20) and leaf acid phosphatase activity (8.90 µmol g^{-1} FW h^{-1}). TCGS-2573 recorded the highest shelling percentage (74.96%), whereas TCGS-2637 registered the maximum phosphorus content (0.49%). Additionally, TCGS-2635 exhibited the highest shelling percentage (77.26%) and Himani recorded the highest root-to-shoot ratio (0.64).

Based on overall per se performance, the genotypes TCGS-2638, TCGS-2572 and TCGS-2634 exhibited outstanding performance for pod yield $plant^{-1}$ and kernel yield $plant^{-1}$ along with several yield-contributing, root and phosphorus use efficiency traits. Therefore, these genotypes may be considered as promising donor parents for the improvement of yield, phosphorus use efficiency and quality traits in groundnut breeding programmes.

Character association

The aim of correlation studies is primarily to determine the suitability of various characters for indirect selection. Correlation studies provide information on the nature and extent of association between different traits and help breeders improve one character through selection for another associated character. The association among root traits, phosphorus use efficiency traits, yield attributes and quality traits in twenty advanced breeding lines along with four check varieties of groundnut was estimated and presented in Table 2 (Figure 1 and 2).

Correlation analysis revealed that kernel yield $plant^{-1}$, number of mature pods $plant^{-1}$, hundred pod weight, harvest index, hundred kernel weight, shelling per cent, phosphorus uptake and phosphorus content exhibited highly significant and positive association with pod yield $plant^{-1}$ at both phenotypic and genotypic levels. Pod yield plant^{-1} showed the highest positive correlation with kernel yield plant^{-1} (r_p = 0.954**, r_g = 0.990**), followed by hundred pod weight (r_p = 0.713**, r_g = 0.756**), number of mature pods plant^{-1} (r_p = 0.703**, r_g = 0.716**), harvest index (r_p = 0.646**, r_g = 0.649**), hundred kernel weight (r_p = 0.554**, r_g = 0.615**), shelling per cent (r_p = 0.546**, r_g = 0.927**), phosphorus uptake (r_p = 0.446**, r_g = 0.470**) and phosphorus content (r_p = 0.374**, r_g = 0.429**). These traits were also positively and significantly associated among themselves in most cases. Therefore, these characters may be considered as important yield-contributing traits and due emphasis should be given to them while selecting for higher pod yield in groundnut.

Number of mature pods plant^{-1} exhibited significant positive association with kernel yield plant^{-1} (r_p = 0.613**, r_g = 0.653**), hundred pod weight (r_p = 0.343*, r_g = 0.369*), shelling per cent (r_g = 0.504*), sound mature kernel per cent (r_g = 0.465*) and harvest index (r_p = 0.553**, r_g = 0.560**), indicating its importance as a major yield component trait. Similarly, phosphorus uptake and phosphorus content were positively associated with several yield attributes, suggesting that improved phosphorus acquisition and utilization contribute to enhanced growth and productivity.

The study on character association further revealed that traits such as kernel yield plant^{-1}, number of mature pods plant^{-1}, harvest index, phosphorus content, phosphorus uptake, shelling per cent, hundred pod weight and hundred kernel weight were positively and significantly associated with pod yield plant^{-1} and among themselves. Hence, improvement in any one of these characters is likely to result in a corresponding increase in pod yield. Therefore, these traits can be considered as reliable selection criteria and may be effectively utilized in breeding programmes aimed at enhancing pod yield and phosphorus use efficiency in groundnut. Similar findings were reported earlier by Bhargavi *et al*. (2015) [3], Yusuf *et al*. (2017), Hampannavar *et al*. (2018), Naga Madhuri *et al*. (2018), Kumar *et al*. (2019), Patel *et al*. (2021), Kadirimangalam *et al*. (2022), Pachauri and Shikarwar (2022), Yadav *et al*. (2023) [9, 14, 16, 26, 41], Killada *et al*. (2023), Kumar *et al*. (2024), Hariharan *et al*. (2025), Mudgalkar *et al*. (2025) and Wadekar *et al*. (2025) [10, 23, 40].

Path Coefficient Analysis

A path coefficient is simply a standardized partial regression coefficient and it measures the direct influence of one trait upon another. In the present study, direct and indirect effects of root traits, phosphorus use efficiency traits, yield and quality traits on pod yield plant^{-1} (g) were worked out and presented in Table 3 (Figure 3 and 4). The residual effects at phenotypic (0.0023) and genotypic (0.0029) levels were very low, indicating the adequacy of the characters chosen for the study. The direct and indirect effects of different component traits on pod yield plant^{-1} (g) are discussed briefly below.

In path analysis, the trait kernel yield plant^{-1} (g) exhibited a high positive direct effect on pod yield plant^{-1} (g) at the phenotypic level. It also possessed significant and positive association with pod yield plant^{-1} (g) (r_p = 0.954**, r_9 = 0.991**). Therefore, kernel yield plant^{-1} (g) plays a major role in determining pod yield plant^{-1} (g) in groundnut. The traits number of mature pods plant^{-1}, hundred pod weight (g), harvest index (%) and phosphorus uptake (kg ha^{-1}) recorded positive direct effects and also exhibited positive association with pod yield plant^{-1} (g).

The traits hundred kernel weight (g), shelling percentage (%) and phosphorus content (%) recorded moderate to high indirect effects through kernel yield plant^{-1} (g), harvest index (%) and number of mature pods plant^{-1} on pod yield plant^{-1} (g). Hence, due emphasis should be placed on kernel yield plant^{-1} (g), number of mature pods plant^{-1}, hundred pod weight (g), harvest index (%) and phosphorus uptake (kg ha^{-1}) for improving pod yield plant^{-1} (g) in groundnut. Similar findings were reported by John *et al*. (2015), Prabhu *et al*. (2017), Patel *et al*. (2021), Patil *et al*. (2024), Mudgalkar *et al*. (2025) and Sukrutha *et al*. (2025) [4, 12, 23, 26, 27, 36].

Conclusion

Based on mean performance and various genetic parameters, the genotypes TCGS-2638, TCGS-2572 and TCGS-2634 were considered superior for pod yield plant^{-1} (g), kernel yield plant^{-1} (g), phosphorus use efficiency traits and other yield-contributing characters in groundnut. High heritability coupled with high genetic advance as per cent of mean was observed for phosphorus uptake (kg ha^{-1}), phosphorus content (%), root dry weight (g), root: shoot ratio, leaf acid phosphatase activity (μ mol g^{-1} FW h^{-1}), kernel yield plant^{-1} (g) and pod yield plant^{-1} (g), indicating the predominance of additive gene action and effectiveness of selection for these traits.

Regarding the correlation analysis, the traits kernel yield plant^{-1} (g), number of mature pods plant^{-1}, hundred pod weight (g), hundred kernel weight (g), shelling percentage (%), harvest index (%), phosphorus uptake (kg ha^{-1}) and phosphorus content (%) were positively associated with pod yield plant^{-1} (g). Therefore, these characters may be considered as important yield-attributing traits and due importance should be given while breeding for high pod yield plant^{-1} (g) and improved phosphorus use efficiency in groundnut.

Similarly, in path analysis, the trait kernel yield plant^{-1} (g) exhibited a high positive direct effect on pod yield plant^{-1} (g). It also possessed significant and positive association with pod yield plant^{-1} (g). Hence, kernel yield plant^{-1} (g) plays a major role in determining pod yield plant^{-1} (g). The traits number of mature pods plant^{-1}, hundred pod weight (g), harvest index (%) and phosphorus uptake (kg ha^{-1}) also exhibited positive direct effects on pod yield plant^{-1} (g). Therefore, due emphasis should be placed on these traits for yield improvement and development of high-yielding phosphorus-efficient groundnut genotypes.

Table 1: *Per se* performance for root traits, phosphorus use efficiency, yield attributes and quality traits in advanced breeding lines of groundnut

Genotypes	DFF	DM	NPB	NMP	HPW	HKW	KYP	SP	SMK	SL	RL	SDW	RDW	R:S	DHY	HI	LAP	P content	P Uptake	OC	PC	PYP
TCGS-2507	25.50	100.00	4.10	15.70	97.20	48.00	9.01	60.35	91.00	40.55	9.15	16.36	5.17	0.32	21.53	40.95	4.10	0.28	0.60	48.81	24.78	14.93
TCGS-2513	27.00	102.00	4.80	17.70	96.20	45.00	11.42	65.50	94.00	41.11	9.61	23.91	9.12	0.38	33.03	34.55	4.20	0.21	0.69	48.52	25.29	17.44
TCGS-2560	26.50	101.00	4.80	14.30	95.59	46.00	8.88	63.79	87.00	33.45	7.82	18.94	1.31	0.07	20.25	40.73	4.80	0.15	0.30	45.96	26.56	13.92
TCGS-2561	30.00	107.00	7.20	23.00	104.01	50.00	13.79	63.93	94.00	42.30	8.40	22.81	4.48	0.20	27.29	44.15	8.90	0.03	0.08	48.30	24.97	21.57
TCGS-2572	27.00	105.00	6.90	24.00	104.97	52.00	15.94	71.96	92.00	38.22	7.98	18.57	4.60	0.25	23.17	48.86	5.60	0.24	0.55	45.91	26.76	22.15
TCGS-2573	30.50	109.00	6.10	18.90	97.49	46.00	14.13	74.96	89.00	36.45	8.96	18.95	3.42	0.18	22.37	45.73	6.20	0.29	0.65	48.61	24.95	18.85
TCGS-2577	28.50	105.00	4.40	17.00	95.18	47.00	11.68	67.57	85.00	41.90	8.17	20.37	2.36	0.12	22.74	43.19	3.20	0.45	1.03	47.71	25.86	17.29
TCGS-2631	27.00	101.00	4.30	22.20	90.26	47.00	12.87	66.70	97.00	31.85	9.36	17.44	6.08	0.35	23.52	45.06	7.00	0.10	0.23	50.20	24.18	19.30
TCGS-2632	29.50	105.00	4.80	20.60	92.47	40.00	9.98	65.14	98.00	33.53	9.92	21.19	11.61	0.55	32.80	31.84	3.30	0.19	0.63	48.34	24.72	15.32
TCGS-2633	26.50	101.00	4.40	19.40	101.00	46.00	14.90	73.65	84.00	33.40	9.03	18.27	3.96	0.22	22.22	47.66	4.10	0.33	0.73	48.21	25.31	20.23
TCGS-2634	28.00	103.00	5.40	22.20	110.43	56.00	18.35	75.01	93.00	42.43	9.58	22.16	7.40	0.33	29.57	45.28	4.30	0.42	1.24	48.51	23.73	24.47
TCGS-2635	26.50	100.00	6.40	20.60	105.83	42.00	16.65	77.26	82.00	33.90	8.61	19.03	4.80	0.25	23.83	47.49	4.00	0.22	0.52	48.96	23.75	21.55
TCGS-2636	28.50	104.00	4.50	19.00	95.95	43.00	13.82	69.90	94.00	33.23	8.28	19.41	4.12	0.21	23.53	45.66	5.20	0.30	0.71	48.59	24.32	19.77
TCGS-2637	27.50	102.00	4.20	16.70	97.21	44.00	10.83	62.62	90.00	44.99	9.58	24.90	7.54	0.30	32.44	34.78	3.80	0.49	1.59	48.64	23.91	17.30
TCGS-2638	29.00	103.00	4.70	16.10	106.28	55.00	17.79	76.98	92.00	50.18	10.15	25.00	10.71	0.43	35.72	39.29	4.70	0.47	1.68	50.36	23.45	23.11
TCGS-2639	29.50	106.00	4.90	19.80	92.94	40.00	13.22	71.36	95.00	32.70	9.30	18.86	2.03	0.11	20.89	47.00	5.50	0.31	0.65	50.84	23.50	18.53
TCGS-2640	29.50	104.00	6.00	17.10	102.20	53.00	12.41	68.30	93.00	32.06	8.96	19.07	5.42	0.28	24.50	42.59	3.10	0.24	0.59	47.12	25.86	18.17

Table 1. (cont.)

Genotypes	DFF	DM	NPB	NMP	HPW	HKW	KYP	SP	SMK	SL	RL	SDW	RDW	R:S	DHY	HI	LAP	P content	P Uptake	OC	PC	PYP
TCGS-2641	26.50	102.00	4.90	16.40	99.29	54.00	11.14	64.90	92.00	45.30	9.50	26.50	6.98	0.26	33.47	33.90	3.00	0.17	0.57	48.66	24.24	17.17
TCGS-2642	29.50	104.00	6.00	14.60	84.81	36.00	8.53	62.04	88.00	39.28	8.90	19.64	4.27	0.22	23.91	36.51	7.00	0.09	0.22	48.48	25.28	13.75
TCGS-2643	26.50	101.00	5.10	15.70	96.38	43.00	10.88	69.98	86.00	32.28	9.92	16.55	8.60	0.52	25.15	38.19	5.90	0.16	0.40	45.98	26.60	15.54
K-6	28.00	103.00	4.60	18.00	93.42	42.00	12.33	71.54	93.00	43.53	9.11	23.54	3.68	0.16	27.22	38.77	3.30	0.25	0.68	47.57	25.14	17.24
DHARANI	28.50	104.00	3.90	17.30	104.34	51.00	14.52	73.29	97.00	39.26	9.28	19.91	2.62	0.13	22.54	46.77	4.00	0.41	0.92	47.86	25.01	19.81
VISISHTA	29.50	105.00	5.00	22.30	100.98	52.00	17.68	71.52	95.00	43.90	8.92	20.63	5.19	0.25	25.82	48.91	5.10	0.38	0.98	49.09	25.22	24.72
HIMANI	28.00	101.50	4.70	19.80	95.69	44.00	14.37	70.41	94.00	30.92	9.60	15.77	10.05	0.64	25.82	44.15	3.60	0.36	0.93	48.70	24.68	20.41
Mean	28.04	103.27	5.09	18.68	98.34	46.75	13.13	69.14	91.46	38.20	9.09	20.32	5.66	0.28	25.97	42.18	4.75	0.27	0.71	48.33	24.92	18.85
Minimum	25.05	100.00	3.90	14.30	84.81	36.00	8.53	60.35	82.00	30.92	7.82	15.77	1.31	0.07	20.25	31.84	3.00	0.03	0.08	45.91	23.45	13.75
Maximum	30.50	109.00	7.20	24.00	110.43	56.00	18.35	77.26	98.00	50.18	10.15	26.50	11.61	0.64	35.72	48.91	8.90	0.49	1.68	50.84	26.76	24.72
C.V.	3.41	1.27	9.67	8.00	1.48	3.26	6.67	5.95	1.92	3.79	6.17	10.72	10.60	20.93	7.60	5.66	7.57	10.26	12.43	0.52	1.91	5.44
S.E.	0.68	0.93	0.35	1.06	1.03	1.08	0.62	2.91	1.24	1.02	0.40	1.54	0.42	0.04	1.40	1.69	0.25	0.02	0.06	0.18	0.34	0.73
C.D.5%	1.98	2.72	1.02	3.09	3.01	3.15	1.81	8.51	3.63	2.99	1.16	4.51	1.24	0.12	4.09	4.94	0.74	0.06	0.18	0.52	0.99	2.12
C.D.1%	2.68	3.69	1.38	4.20	4.09	4.27	2.47	11.55	4.92	4.06	1.57	6.12	1.68	0.17	5.54	6.70	1.01	0.08	0.24	0.71	1.34	2.88

DFF: Days to 50% flowering DM: Days to maturity NPB: Number of primary branches plant^{-1} NMP: Number of mature pods plant^{-1} HPW: Hundred pod weight (g) HKW: Hundred kernel weight (g) PYP: Pod yield plant^{-1} (g) KYP: Kernel yield plant^{-1}(g) SP: Shelling per cent SMK: Sound mature kernel per cent SL: Shoot length (cm) RL: Root length (cm) SDW: Shoot dry weight (g) RDW: Root dry weight (g) R:S: Root: shoot ratio DHY: Dry haulms yield (g) HI: Harvest index (%) LAP: Leaf acid phosphatase (μ mol g^{-1} FW h^{-1}) P content: Phosphorus content (%) P uptake: Phosphorus uptake (kg ha^{-1})

Table 2: Phenotypic (r_p) and genotypic (r_g) correlation coefficients among root traits, phosphorus use efficiency, yield attributes and quality traits in groundnut genotypes

Traits		DF	DM	NPB	NMP	HPW	HKW	KYP	SP	SMK	SL	RL	SDW	RDW	R:S	DHY	HI	LAP	P content	P uptake	OC	PC	Correlation with PYP
DF	rp	1.000	0.718**	0.214	0.129	-0.095	-0.048	0.152	0.117	0.334*	0.073	-0.079	0.177	-0.058	-0.149	0.088	0.045	0.255	0.040	0.238	0.215	-0.084	0.164
	rg	1.000	0.977**	0.471*	0.315	-0.034	-0.039	0.277	0.259	0.428*	0.100	0.182	0.122	-0.062	-0.112	0.029	0.208	0.354	0.145	0.336	0.334	-0.245	0.290
DM	rp		1.000	0.266	0.330*	-0.034	-0.005	0.153	0.139	0.338*	0.076	-0.086	0.093	-0.238	-0.287*	-0.080	0.192	0.316*	0.055	0.085	0.171	-0.006	0.163
	rg		1.000	0.473*	0.362*	-0.034	-0.026	0.179	0.048	0.453*	0.082	-0.367	0.216	-0.336	-0.441*	-0.096	0.282	0.362*	0.018	0.107	0.178	-0.087	0.245
NPB	rp			1.000	0.372**	0.264	0.093	0.206	0.066	-0.159	-0.033	-0.288*	-0.033	-0.085	-0.062	-0.074	0.221	0.459**	-0.427**	-0.246	-0.214	0.140	0.241
	rg			1.000	0.469**	0.329	0.072	0.269	0.256	-0.197	-0.087	-0.557**	0.002	-0.137	-0.155	-0.088	0.254	0.548**	-0.521**	-0.304	-0.275	0.309	0.281
NMP	rp				1.000	0.343*	0.199	0.613**	0.271	0.273	-0.092	-0.031	-0.097	0.045	0.093	-0.040	0.553**	0.272	-0.050	0.105	0.177	-0.128	0.703**
	rg				1.000	0.369*	0.233	0.653**	0.504*	0.465*	-0.172	-0.348	-0.093	0.067	0.085	-0.009	0.560**	0.345	-0.068	0.118	0.184	-0.207	0.716**
HPW	rp					1.000	0.739**	0.727**	0.502**	-0.058	0.298*	0.006	0.207	0.067	-0.024	0.184	0.393**	-0.132	0.367*	0.364*	-0.088	-0.107	0.713**
	rg					1.000	0.790**	0.749**	0.658**	-0.062	0.323*	-0.075	0.233	0.089	-0.002	0.191	0.444**	-0.136	0.374*	0.388*	-0.103	-0.154	0.756**
HKW	rp						1.000	0.489**	0.170	0.203	0.432**	0.033	0.230	0.093	-0.010	0.216	0.251	-0.120	0.297*	0.232	-0.045	-0.017	0.554**
	rg						1.000	0.562**	0.365	0.208	0.486**	0.010	0.393	0.083	-0.042	0.278	0.258	-0.112	0.299*	0.251	-0.054	-0.013	0.615**
KYP	rp							1.000	0.767**	0.069	0.183	0.015	0.087	0.056	0.009	0.094	0.637**	0.056	0.428**	0.497**	0.272	-0.288*	0.954**
	rg							1.000	0.970**	0.119	0.184	0.082	0.060	0.096	0.068	0.096	0.698**	0.035	0.472**	0.516**	0.282	-0.395*	0.991**
SP	rp								1.000	−0.108	-0.027	0.020	0.017	-0.029	-0.051	-0.006	0.417**	-0.051	0.369**	0.399**	0.130	-0.124	0.546**
	rg								1.000	-0.153	-0.065	0.273	-0.229	0.008	0.063	-0.126	0.844**	-0.199	0.533**	0.569**	0.153	-0.387	0.927**
SMK	rp									1.000	0.072	0.234	0.129	0.266	0.205	0.251	-0.070	0.082	-0.017	0.144	0.299*	-0.255	0.160
	rg									1.000	0.074	0.489*	0.252	0.301	0.242	0.340	-0.074	0.054	-0.012	0.149	0.345*	-0.269	0.230
SL	rp										1.000	0.159	0.695**	0.135	-0.132	0.564**	-0.266	-0.081	0.339*	0.336*	0.184	-0.223	0.239
	rg										1.000	0.208	0.925**	0.143	-0.146	0.621**	-0.295	-0.094	0.374*	0.353*	0.191	-0.265	0.247
RL	rp											1.000	0.146	0.668**	0.634**	0.506**	-0.377**	-0.208	0.228	0.340*	0.372**	-0.389**	0.003
	rg											1.000	0.456*	0.953**	0.801**	0.882**	-0.667**	-0.282	0.221	0.576**	0.527**	-0.607**	0.010

Table 2. (cont.)

Traits		DF	DM	NPB	NMP	HPW	HKW	KYP	SP	SMK	SL	RL	SDW	RDW	R:S	DHY	HI	LAP	P content	P uptake	OC	PC	Correlation with PYP
SDW	rp												1.000	0.180	-0.197	0.803**	-0.524 **	-0.174	0.111	0.265	0.167	-0.213	0.112
	rg												1.000	0.336	0.006	0.789**	-0.475**	-0.221	0.223	0.440*	0.229	-0.557**	0.150
RDW	rp													1.000	0.916**	0.731**	-0.505 **	-0.201	0.089	0.434**	0.184	-0.262	0.080
	rg													1.000	0.941**	0.844**	-0.571**	-0.210	0.075	0.448**	0.182	-0.266	0.117
R:S	rp														1.000	0.419**	-0.309 *	-0.142	0.037	0.289*	0.092	-0.160	0.030
	rg														1.000	0.618**	-0.442*	-0.158	-0.008	0.299*	0.086	-0.084	0.068
DHY	rp															1.000	-0.670**	-0.242	0.131	0.447**	0.228	-0.306*	0.126
	rg															1.000	-0.643 **	-0.263	0.176	0.543**	0.249	-0.491*	0.162
HI	rp																1.000	0.247	0.195	-0.013	0.068	-0.014	0.646**
	rg																1.000	0.284	0.217	-0.054	0.078	0.053	0.649**
LAP	rp																	1.000	-0.506**	-0.420**	0.111	0.070	0.110
	rg																	1.000	-0.543**	-0.459**	0.096	0.067	0.129
P content	rp																		1.000	0.741**	0.233	-0.301 *	0.374**
	rg																		1.000	0.768**	0.219	-0.328*	0.429**
P uptake	rp																			1.000	0.313*	-0.448**	0.446**
	rg																			1.000	0.321*	-0.482**	0.470**

OC	rp																				1.000	-0.813**	0.291
	rg																				1.000	-0.945**	0.313
PC	rp																					1.000	-0.307
	rg																					1.000	-0.381
PYP	rp																						1.000
	rg																						1.000

*Significance at 5% level; ** Significance at 1% level.

DFF: Days to 50% flowering DM: Days to maturity NPB: Number of primary branches plant^{-1} NMP: Number of mature pods plant^{-1} HPW: Hundred pod weight (g) HKW: Hundred kernel weight (g) PYP: Pod yield plant^{-1} (g) KYP: Kernel yield plant^{-1}(g) SP: Shelling per cent SMK: Sound mature kernel per cent SL: Shoot length (cm) RL: Root length (cm) SDW: Shoot dry weight (g) RDW: Root dry weight (g) R:S: Root: shoot ratio DHY: Dry haulms yield (g) HI: Harvest index (%)LAP: Leaf acid phosphatase (µ mol g^{-1} FW h^{-1}) P content: Phosphorus content (%) P uptake: Phosphorus uptake (kg ha^{-1})

Table 3: Phenotypic (P) and genotypic (G) path coefficients for root traits, phosphorus use efficiency, yield attributes and quality in groundnut genotypes

Traits		DFF	DM	NPB	NMP	HPW	HKW	KYP	SP	SMK	SL	RL	SDW	RDW	R:S	DHY	HI	LAP	P content	P Uptake	OC	PC	Correlation with PYP
DFF	P	0.0341	-0.0037	-0.0065	0.0048	-0.0008	0.0004	0.1429	-0.0369	0.0004	0.0011	0.0006	-0.2484	0.0749	-0.0091	0.2043	0.0160	0.0020	-0.0004	-0.0060	-0.0062	0.0008	0.1641
	G	0.2698	-0.2555	-0.0811	0.1254	-0.0126	0.0034	-0.8338	0.2347	-0.0444	0.0686	0.0049	0.1434	-0.0521	-0.0727	0.0054	0.7112	-0.0081	-0.0699	0.1386	0.1058	-0.0908	0.2901
DM	P	0.0245	-0.0051	-0.0081	0.0122	-0.0003	0.0000	0.1440	-0.0439	0.0004	0.0012	0.0006	-0.1304	0.3080	-0.0178	-0.1861	0.0683	0.0025	-0.0005	-0.0021	-0.0050	0.0001	0.1625
	G	0.2636	-0.2615	-0.0814	0.1440	-0.0125	0.0023	-0.5389	0.0436	-0.0471	-0.0563	0.0099	0.2543	-0.2808	-0.2867	-0.0178	0.9661	-0.0083	-0.0087	0.0442	0.0565	-0.0323	0.2449
NPB	P	0.0073	-0.0014	-0.0304	0.0137	0.0023	-0.0007	0.1934	-0.0210	-0.0002	-0.0005	0.0021	0.0457	0.1093	-0.0039	-0.1719	0.0785	0.0036	0.0042	0.0061	0.0062	-0.0013	0.2414
	G	0.1272	-0.1237	-0.1721	0.1866	0.1218	-0.0063	-0.8099	0.2320	0.0205	-0.0592	-0.0150	0.0019	-0.1142	-0.1004	-0.0164	0.8677	-0.0125	0.2507	-0.1254	-0.0872	0.1143	0.2805
NMP	P	0.0044	-0.0017	-0.0113	0.0369	0.0030	-0.0015	0.5763	-0.0857	0.0003	-0.0014	0.0002	0.1356	-0.0579	0.0057	-0.0926	0.1969	0.0021	0.0005	-0.0026	-0.0052	0.0012	0.7031 **
	G	0.0851	-0.0947	-0.0808	0.3976	0.1369	-0.0203	-1.9629	0.4577	-0.0483	-0.1178	-0.0093	-0.1098	0.0560	0.0555	-0.0018	1.9178	-0.0079	0.0327	0.0488	0.0584	-0.0767	0.7162 **
HPW	P	-0.0032	0.0002	-0.0081	0.0127	0.0086	-0.0055	0.6831	-0.1588	-0.0001	-0.0046	0.0000	-0.2902	-0.0859	-0.0015	0.4276	0.1398	-0.0010	-0.0036	-0.0091	0.0026	0.0010	0.7132 **
	G	-0.0092	0.0088	-0.0566	0.1469	0.3705	-0.0688	-2.2522	0.5970	0.0065	-0.2211	0.0020	0.2737	0.0746	-0.0016	0.0355	1.5184	0.0031	-0.1801	0.1601	-0.0325	-0.0569	0.7563 **
HKW	P	-0.0016	0.0000	-0.0028	0.0073	0.0064	-0.0075	0.4594	-0.0537	0.0002	-0.0067	0.0002	-0.3226	-0.1195	-0.0006	0.5019	0.0894	-0.0009	-0.0029	-0.0058	0.0013	0.0002	0.5545 **
	G	-0.0104	0.0068	-0.0124	0.0927	0.2927	-0.0871	-1.6891	0.3314	-0.0216	0.3322	0.0003	0.4624	0.0690	-0.0273	0.0516	0.8843	0.0025	-0.1442	0.1034	-0.0172	-0.0049	0.6151 **
KYP	P	0.0052	-0.0008	-0.0063	0.0226	0.0063	-0.0037	0.9396	-0.2428	0.0001	-0.0028	0.0001	-0.1222	-0.0722	0.0006	0.2196	0.2268	0.0004	-0.0042	-0.0124	-0.0079	0.0026	0.9541 **
	G	0.0749	-0.0469	-0.0464	0.2597	0.2776	-0.0489	-3.0060	0.8806	-0.0123	0.1262	0.0022	0.0704	0.0798	0.0445	0.0179	2.3897	-0.0008	-0.2271	0.2129	0.0893	-0.1464	0.9908 **
SP	rp	0.0040	-0.0007	-0.0020	0.0100	0.0043	-0.0013	0.7206	-0.3166	-0.0001	-0.0004	-0.0002	-0.0238	0.0379	-0.0032	-0.0140	0.1485	-0.0004	-0.0036	-0.0100	-0.0038	0.0011	0.5464 **
	rg	0.0698	-0.0126	-0.0440	0.2006	0.2437	-0.0318	-2.9171	0.9074	0.0159	-0.0445	0.0073	-0.2695	0.0065	0.0411	-0.0233	2.8896	0.0045	-0.2565	0.2345	0.0484	-0.1431	0.9269 **
SMK	P	0.0114	-0.0017	0.0048	0.0101	-0.0005	-0.0015	0.0653	0.0343	0.0011	-0.0011	0.0017	-0.1808	-0.3442	0.0128	0.5838	-0.0249	0.0006	0.0002	-0.0036	-0.0087	0.0023	0.1600
	G	0.1155	-0.1185	0.0339	0.1850	-0.0230	-0.0181	-0.3570	-0.1390	-0.1039	0.0508	0.0131	0.2963	0.2515	0.1575	0.0631	-0.2527	-0.0012	0.0057	0.0614	0.1092	-0.0996	0.2300
SL	P	0.0025	-0.0004	0.0010	-0.0034	0.0026	-0.0032	0.1724	0.0086	0.0001	-0.0154	0.0012	-0.9740	-0.1748	-0.0082	1.3120	-0.0946	-0.0006	-0.0033	-0.0084	-0.0054	0.0020	0.2392
	G	0.0271	-0.0215	0.0149	-0.0685	0.1197	-0.0423	-0.5544	-0.0591	-0.0077	0.6840	0.0056	1.0882	0.1197	-0.0950	0.1153	-1.0093	0.0021	-0.1800	0.1456	0.0606	-0.0981	0.2469
RL	P	-0.0027	0.0004	0.0088	-0.0011	0.0001	-0.0002	0.0140	-0.0063	0.0003	-0.0025	0.0074	-0.2050	-0.8632	0.0394	1.1780	-0.1345	-0.0016	-0.0023	-0.0085	-0.0108	0.0035	0.0034
	G	0.0492	0.0961	0.0960	-0.1383	-0.0279	-0.0008	-0.2453	0.2473	-0.0508	0.1421	0.0269	0.5368	0.7967	0.5204	0.1639	-2.2812	0.0064	-0.1065	0.2373	0.1671	-0.2246	0.0104
SDW	P	0.0061	-0.0005	0.0010	-0.0036	0.0018	-0.0017	0.0819	-0.0054	0.0001	-0.0107	0.0011	-1.4018	-0.2332	-0.0122	1.8681	-0.1866	-0.0014	-0.0011	-0.0066	-0.0049	0.0019	0.1115
	G	0.0329	-0.0566	-0.0003	-0.0371	0.0863	-0.0343	-0.1801	-0.2080	-0.0262	0.6330	0.0123	1.1758	0.2810	0.0037	0.1466	-1.6245	0.0050	-0.1074	0.1812	0.0725	-0.2062	0.1497
RDW	P	-0.0020	0.0012	0.0026	0.0017	0.0006	-0.0007	0.0525	0.0093	0.0003	-0.0021	0.0049	-0.2530	-1.2920	0.0570	1.7015	-0.1798	-0.0016	-0.0009	-0.0108	-0.0054	0.0024	0.0799
	G	-0.0168	0.0879	0.0235	0.0267	0.0331	-0.0072	-0.2870	0.0070	-0.0313	0.0980	0.0256	0.3952	0.8359	0.6113	0.1568	-1.9545	0.0048	-0.0361	0.1848	0.0578	-0.0986	0.1169
R:S	P	-0.0050	0.0015	0.0019	0.0034	-0.0002	0.0001	0.0086	0.0163	0.0002	-0.0020	-0.0047	0.2753	-1.1851	0.0626	0.9767	-0.1100	-0.0011	-0.0005	-0.0073	-0.0028	0.0014	0.0301
	G	-0.0302	0.1154	0.0266	0.0340	-0.0009	0.0037	-0.2057	0.0574	-0.0252	-0.1000	0.0215	0.0066	0.7865	0.6494	0.1147	-1.5132	0.0036	0.0039	0.1236	0.0272	-0.0311	0.0678
DHY	P	0.0030	0.0004	0.0023	-0.0015	0.0016	-0.0016	0.0887	0.0019	0.0003	-0.0087	0.0037	-1.1255	-0.9448	0.0261	2.3267	-0.2384	-0.0019	-0.0013	-0.0112	-0.0066	0.0028	0.1258
	G	0.0078	0.0251	0.0152	-0.0038	0.0707	-0.0242	-0.2898	-0.1139	-0.0353	0.4245	0.0237	0.9276	0.7055	0.4010	0.1858	-2.2006	0.0060	-0.0847	0.2238	0.0790	-0.1818	0.1615
HI	P	0.0015	-0.0010	-0.0067	0.0204	0.0034	-0.0019	0.5987	-0.1321	-0.0001	-0.0041	0.0028	0.7350	0.6526	-0.0192	-1.5582	0.3560	0.0019	-0.0019	0.0003	-0.0020	0.0001	0.6457 **
	G	0.0561	-0.0738	-0.0436	0.2228	0.1644	-0.0225	-2.0991	0.7662	0.0077	-0.2017	-0.0179	-0.5582	-0.4774	-0.2873	-0.1195	3.4221	-0.0065	-0.1046	-0.0222	0.0247	0.0195	0.6493 **

LAP	P	0.0087	-0.0016	-0.0140	0.0100	-0.0011	0.0009	0.0530	0.0163	0.0001	-0.0012	0.0015	0.2435	0.2596	-0.0088	-0.5640	0.0878	0.0078	0.0050	0.0105	-0.0032	-0.0006	0.1101
	G	0.0955	-0.0948	-0.0943	0.1373	-0.0503	0.0097	-0.1051	-0.1805	-0.0056	-0.0643	-0.0076	-0.2599	-0.1754	-0.1027	-0.0488	0.9713	-0.0228	0.2612	-0.1891	0.0304	0.0247	0.1291
P content	P	0.0014	-0.0003	0.0131	-0.0019	0.0032	-0.0022	0.4040	-0.1168	0.0000	-0.0052	0.0017	-0.1559	-0.1143	0.0033	0.3041	0.0698	-0.0039	-0.0098	-0.0182	-0.0068	0.0027	0.3741 **
	G	0.0392	-0.0047	0.0897	-0.0270	0.1386	-0.0261	-1.4180	0.4837	0.0012	0.2558	0.0059	0.2624	0.0627	-0.0053	0.0327	0.7434	0.0124	-0.4810	0.3165	0.0693	-0.1215	0.4297 **
P Uptake	P	0.0082	-0.0004	0.0075	0.0039	0.0031	-0.0017	0.4674	-0.1265	0.0002	-0.0052	0.0025	-0.3715	-0.5605	0.0182	1.0402	-0.0048	-0.0033	-0.0072	-0.0249	-0.0091	0.0041	0.4456 **
	G	0.0907	-0.0280	0.0524	0.0470	0.1439	-0.0218	-1.5523	0.5164	-0.0155	0.2416	0.0155	0.5170	0.3749	0.1948	0.1009	-0.1839	0.0104	-0.3696	0.4122	0.1016	-0.1784	0.4698 **
OC	P	0.0073	-0.0009	0.0065	0.0065	-0.0008	0.0003	0.2561	-0.0412	0.0003	-0.0028	0.0027	-0.2350	-0.2376	0.0059	0.5298	0.0241	0.0009	-0.0023	-0.0078	-0.0291	0.0074	0.2906
	G	0.0901	-0.0466	0.0474	0.0732	-0.0380	0.0047	-0.8474	0.1387	-0.0358	0.1308	0.0142	0.2692	0.1525	0.0557	0.0463	0.2665	-0.0022	-0.1052	0.1322	0.3168	-0.3498	0.3130
PC	P	-0.0029	0.0000	-0.0042	-0.0047	-0.0009	0.0001	-0.2706	0.0394	-0.0003	-0.0035	0.0029	0.2980	0.3385	-0.0098	-0.7129	-0.0051	0.0006	0.0029	0.0112	0.0237	-0.0090	-0.3065
	G	-0.0662	0.0228	-0.0532	-0.0824	-0.0569	0.0012	1.1887	-0.3509	0.0279	-0.1813	-0.0163	-0.6552	-0.2227	-0.0546	-0.0913	0.1805	-0.0015	0.1580	-0.1987	-0.2995	0.3701	-0.3813

DFF: Days to 50% flowering DM: Days to maturity NPB: Number of primary branches plant^{-1} NMP: Number of mature pods plant^{-1} HPW: Hundred pod weight (g HKW: Hundred kernel weight (g) PYP: Pod yield plant^{-1} (g) KYP: Kernel yield plant^{-1}(g) SP: Shelling per cent SMK: Sound mature kernel per cent SL: Shoot length (cm) RL: Root length (cm) SDW: Shoot dry weight (g) RDW: Root dry weight (g) R:S: Root: shoot ratio DHY: Dry haulms yield (g) HI: Harvest index (%) LAP: Leaf acid phosphatase (µ mol g^{-1} FW h^{-1}) P content: Phosphorus content (%) P uptake: Phosphorus uptake (kg ha^{-1})

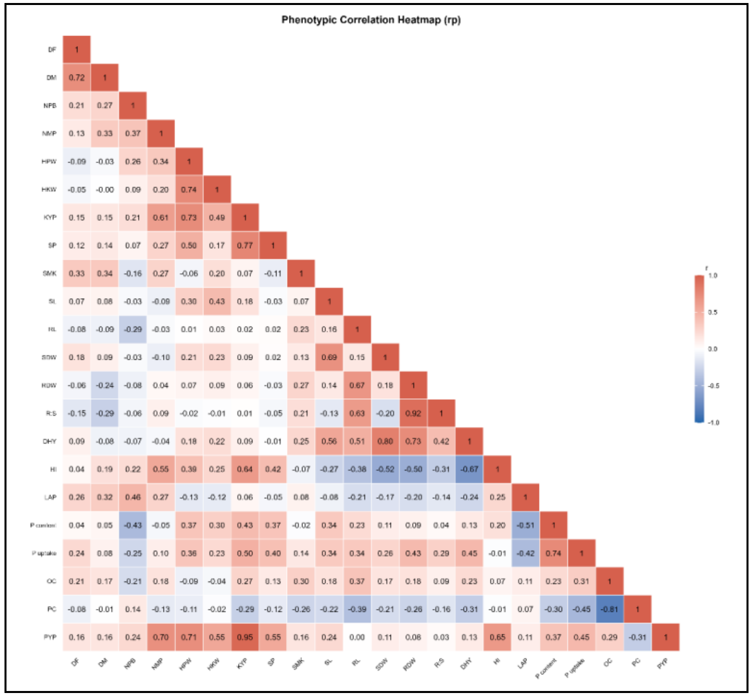

Fig 1: Heatmap showing genotypic correlations for genotypic twenty-two traits through shaded correlation matrix

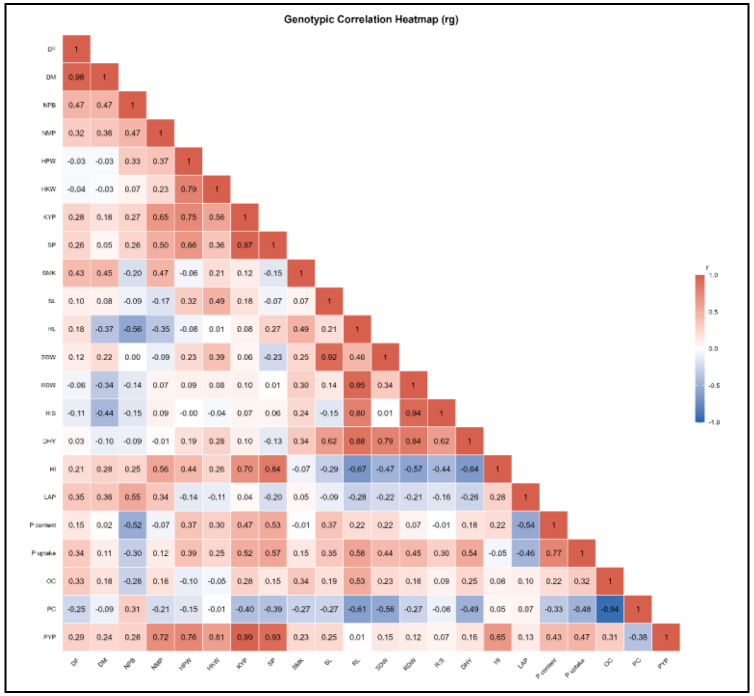

Fig 2: Heatmap showing phenotypic correlations for twenty-two traits through shaded correlation matrix

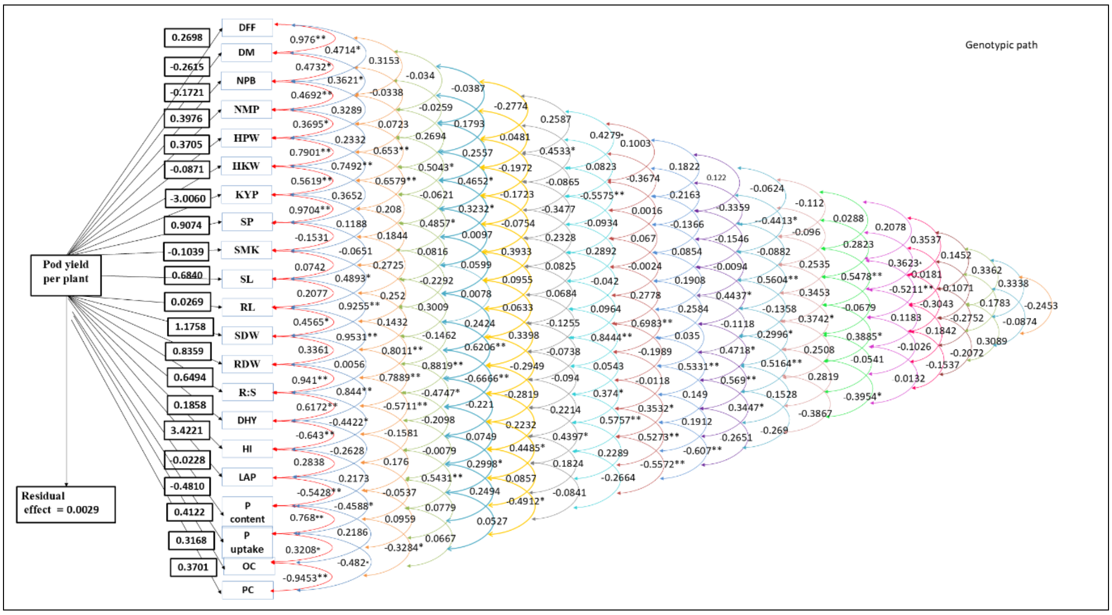

Fig 3: Genotypic path diagram of pod yield plant^{-1} and its component traits

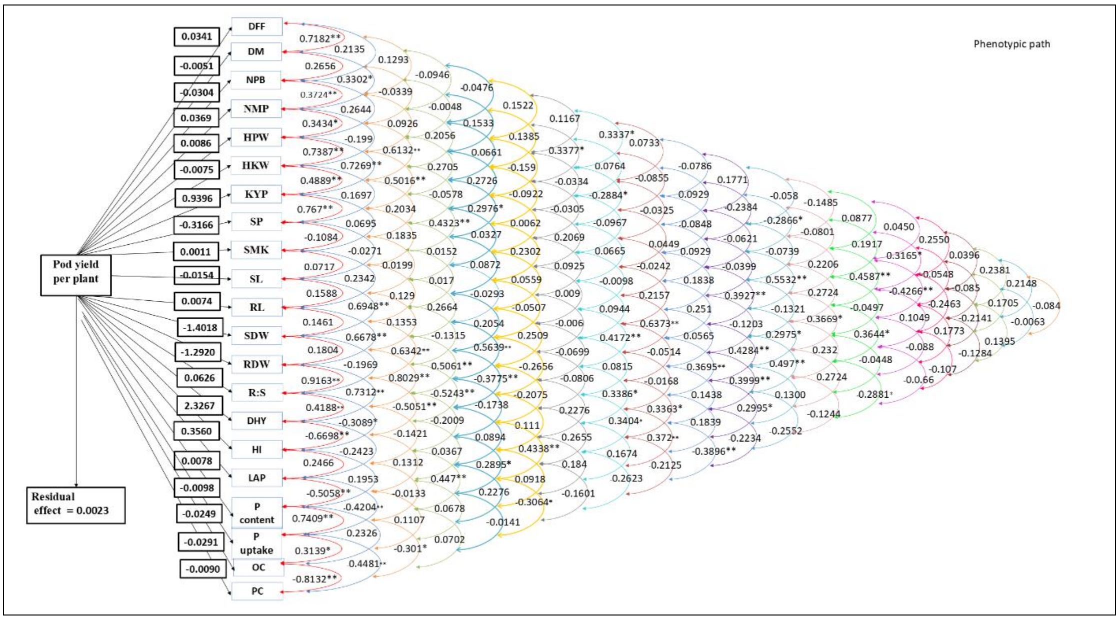

Fig 4: Phenotypic path diagram of pod yield plant^{-1} and its component traits

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