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Response of different peanut genotypes to reduced phosphorous availability

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Abstract

Performances of 23 peanut genotypes comprising of popular varieties and few widely used germplasm accessions were compared under P-unfertilized and P-fertilized conditions during *kharif* and summer seasons to identify P-efficient and P-inefficient genotypes. Yield parameters and P concentrations in different plant parts at maturity were recorded and P-efficiency indices calculated. Significant differences among peanut genotypes, P levels and P × genotype interactions were observed for all the traits. LP caused 33% and 23% yield reduction during *kharif* and summer season respectively. However, performance of genotypes varied with the season and P supply. Genotypes FeESG-10, GG-7, GG-20 and TG-37A with high yield, kernel P-uptake and P concentration in leaf were P-efficient. On the contrary genotypes NRCG-162, GPBD-4, NRCG-7320 and NRCG-7085 were identified as P-inefficient. As an immediate solution to P deficient soils, the P-efficient genotypes could be directly grown in the LP soils with/ without using P to get high yield.

Key words: Peanut, P-unfertilized, P-fertilized, P efficiency, P uptake

Introduction

The peanut (*Arachis hypogaea* L.) is grown predominantly by small farmers in tropical and subtropical regions under light textured soils with frequent drought and soil infertility affecting yield (Singh 2011). Crop yield on 30-40% of world's arable land is limited by low P availability (Runge-Metzger 1995) as majority of applied P is transformed into insoluble form. Problem is further aggravated by inadequate and imbalanced use of fertilizers leading to reduced nutrient availability for crop growth finally affecting yield (Singh and Basu 2005). Hence, average peanut yield is less than 1000 kg/ha in more than 50% of the peanut growing countries of the world against world average of 1650 kg/ha (FAO 2013). Thus genotypes that can acquire and use P resources more efficiently from soils are more desirable as they avoid soil-P depletion, economical and stabilise yields (Singh and Basu 2005).

In peanut, studies related to low P tolerance are very limited and there are no well-defined selection criteria. Genotypes ICGV-86590, ICG-14475, mutant-68 and ICGV-92188 were identified as P-responsive based on in-vitro root morphogenetic studies (Kumar et al. 2009). Root hair like growth on pegs contribute to variation in phosphorus (P) uptake (Wissuwa and Ae 1999). Genotypes SAMNUT-10 and 21 were identified for low soil P conditions and for resource-poor farmers (Gabasawa and Yusuf 2013). Field studies involving large scale screening of peanut genotypes under P-unfertilized (LP) availability is very limited. Hence, the objective of the present study was to study the response of peanut genotypes to LP availability and determining their P efficiency index (PEI), P response efficiency (PRE), P stress factor (PSF) and P use efficiency.

Materials and methods

Site description and experimental study

The field screening, for two consecutive seasons during summer and rainy (*Kharif*), was conducted at the ICAR-Directorate of Groundnut Research, Junagadh), India in a medium black calcareous (17% $CaCO_3$) clayey, VerticUstochrept soil having 15kg/ha available P, pH 7.5, 0.7% organic C, 268kg/ha N, 300-400kg/ha K and 5kg/ha available S. Experiment was laid out in a split plot design with P levels in main plot and genotypes in sub-plot with two replications.

Twenty three peanut genotypes (12 varieties and

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13 germplasms) were grown under P-unfertilized and P-fertilized (50kg/ha P_2O_5as diammonium phosphate, HP) condition. Nitrogen as Urea at 50kg/ha N and K as murate of potash at 60kg/haK_2O were applied as basal commonly in both the treatments. In P-fertilized (HP), treatment, the N was calculated after deducting the contributions by DAP. The crop was raised following standard package of practices, harvested at maturity, dried in sun and per plant pods (PY) and kernel yields (KY) were recorded. At maturity five plants were uprooted, washed, separated into leaves, stem and pods, dried in oven at 70°C for five days and dry weight was recorded. These samples were ground to a fine powder and the P concentrations in leaf (PC_L), shoot (PC_S) and kernels (PC_K) were estimated following Fiske and Subbarao (1925). The kernel P-uptake (P_K) was obtained as a product of PC_K and KY.

The phosphorous stress factor (PSF) and P-efficiency index (PEI) (Singh et al. 2015) and P response efficiency (PRE) (Pang et al. 2010) were calculated. Phosphorus use efficiency (PUE) for HP treatment was calculated as a ratio of kg kernel yield produced (KY) per kg of fertilizer P applied (Ajay et al 2015).

Statistical analysis

All the data were analysed statistically by ANOVA using DSAASTAT (Onofri 2007). Genotype-by-trait (GT) biplot was constructed by the principal component analysis using PAST statistical software (Hammer et al. 2001). Genotypes with P efficiency indices more than mean-plus-standard deviation were classified as P-efficient and genotypes with P efficiency indices less than mean-minus-standard deviation were classified as P-inefficient.

Results and discussion

Pod and kernel yield

There were significant genotypic differences for PY, KY, (Table 1; Figs. 1 and 3). The mean PY were 4.5 and 3.0g/plant under HP and LP, respectively during *kharif*, but 19.2 and 14.6g/plant, respectively during summer with a reduction of 33 and 23% under LP during *kharif* and summer seasons, respectively (Table 1). In general PY and KY during summer were higher than that of *kharif* (Table 1) due to more sunshine

Table 1. Average values for per plant pod (PY) and kernel yield (KY), kernel P-uptake (P_K), leaf P-concentration (PC_L), shoot P-concentration (PC_S) and kernel P-concentration (PC_K) in peanut genotypes

Trait	Season	Treatment	Average	Range	% reduction	Paired t-test (P@0.05)
PY (g/plant)	*Kharif*	HP	4.5	1.8-6.3	32.5	<0.0001
		LP	3.0	0.8-5.0		
	Summer	HP	19.2	9.3-30.0	22.6	<0.0001
		LP	14.6	7.2-26.4		
kernel yield (g/plant)	*Kharif*	HP	3.0	0.5-4.6	30.6	<0.0001
		LP	2.0	0.4-3.5		
	Summer	HP	11.5	5.5-16.5	22.9	0.0001
		LP	8.5	4.9-13.9		
P_K (mg/plant)	*Kharif*	HP	12.8	2.2-21.2	23.6	0.001
		LP	9.4	2.1-15.1		
	Summer	HP	43.2	20.2-67.9	14.0	0.006
		LP	35.6	20.3-51.6		
PC_L (mg/g)	*Kharif*	HP	1.8	1.5-2.5	6.0	0.06
		LP	1.7	1.2-2.3		
	Summer	HP	1.7	1.0-2.3	8.2	0.08
		LP	1.6	1.0-2.8		
PC_K (mg/g)	*Kharif*	HP	4.2	3.0-5.2	-10.0	0.009
		LP	4.6	3.7-5.4		
	Summer	HP	3.8	3.2-4.4	-12.9	0.0008
		LP	4.2	3.5-5.3		
PC_S (mg/g)	*Kharif*	HP	1.8	1.1-2.6	0.8	0.375
		LP	1.7	1.4-2.4		
	Summer	HP	1.3	0.9-1.8	-0.2	0.95
		LP	1.3	0.8-2.2		

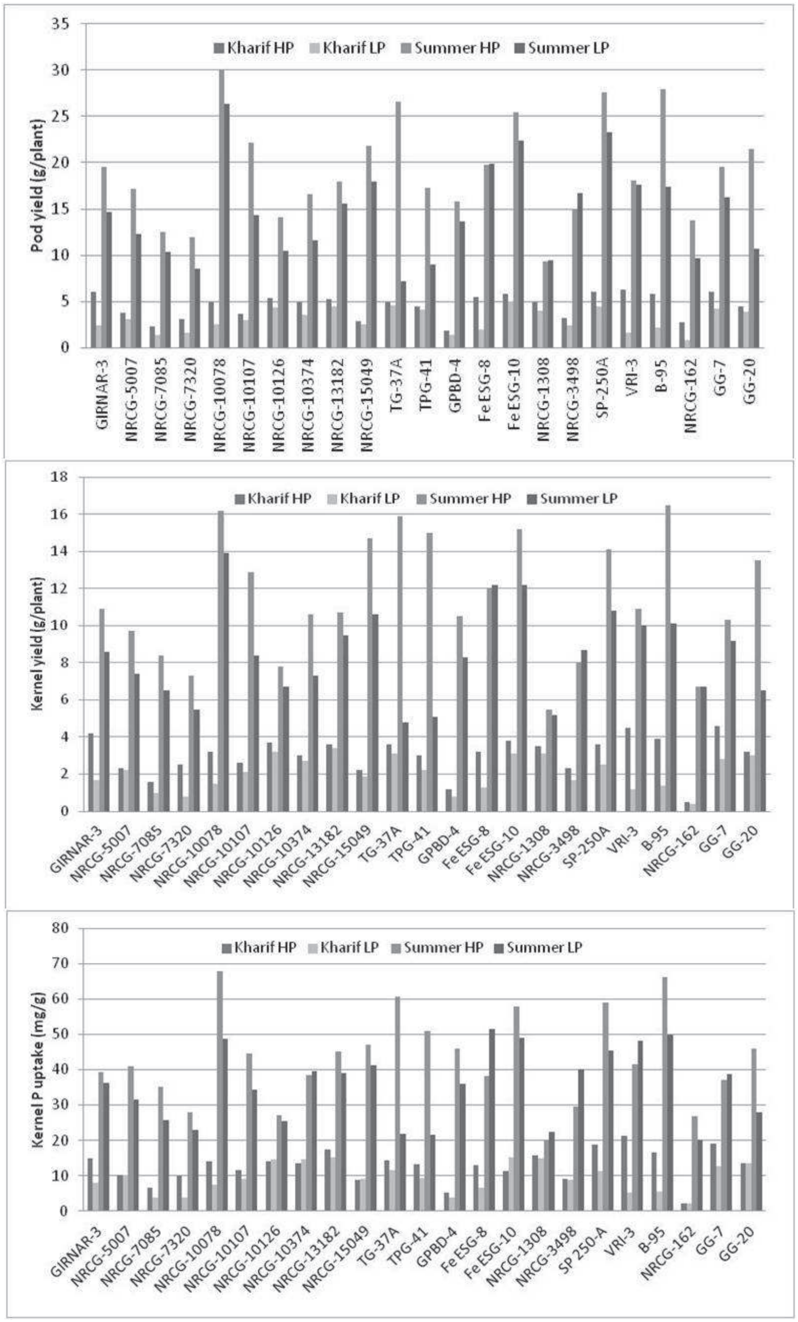

Fig. 1. Pod yield, kernel yield and kernel-P uptake among peanut genotypes

hours and favorable environmental conditions (Nautiyal et al. 2012). The cultivar TG-37A showed lower yield reduction during *kharif*, but genotypes NRCG-10078, NRCG-13182, GPBD-4 and FeESG-10 recorded <15% yield reduction during summer (Figs. 1 and 3). The KY was 3.0 and 2.0g/plant under HP and LP, respectively during *kharif* and 11.5 and 8.5g/plant respectively during summer (Table 1) with 31 and 23% reduction during *kharif* and summer seasons under LP; however GG-20 and NRCG-3498 showed lower KY reduction during *kharif* and summer seasons, respectively. Genotypes GG-7, B-95, SP-250A, FeESG-8, and NRCG-13182 showed high KY under both P levels (Figs. 1 and 3) and hence were P-efficient. Genotypes which sustained yield under LP were considered as P-efficient (Mourice and Tryphone 2012). On the other hand genotypes GPBD-4, NRCG-162, NRCG-7085, NRCG-3498 and NRCG-7320 were low yielders and P-inefficient. These efficient and inefficient genotypes formed separate clusters in GT-biplot (Fig. 4).

Significant differences between P and P×genotype interactions for KY, PY, PC_L, PC_K and P_K indicates that reduction in P supply may increase or decrease the performance of genotypes and some genotypes are highly responsive to P fertilization. This is in agreement with studies by Ibrahim and Eleiwa (2008) and Singh et al. (2015) who reported increase in pod yield with increase in P application. However, yield increased until a limit is reached (Singh and Chaudhari 2007). Significant season × genotype interactions for most traits indicated seasonal variation in genotypic expression. Significant genotypic variation and genotype×P interaction for PRE (yield increase per unit P uptake) and PUE (yield produced per unit kg of fertilizer applied) indicated that it is possible to increase yield per unit of available plant P if the genotypes are capable of growing well under both LP and HP. In this study PRE at LP was greater than at HP which is obvious and corroborates our earlier study (Singh and Chaudhari 2007). Significant season×P×genotype interactions for all traits indicate that response of genotypes to P levels vary with seasons.

P concentrations in leaf, stem and kernel and kernel P uptake

There were significant genotypic differences for P concentrations in leaf (PC_L), shoot (PC_S) and kernels (PC_K) and kernel P-uptake (P_K) (Table 1; Figs. 1-3). Mean PC_L during *kharif* was 1.8 and 1.7 mg/g under HP and LP, respectively while during summer these were 1.7 and 1.6mg/g, respectively. Similarly PC_s was 1.8 and 1.7 mg/g

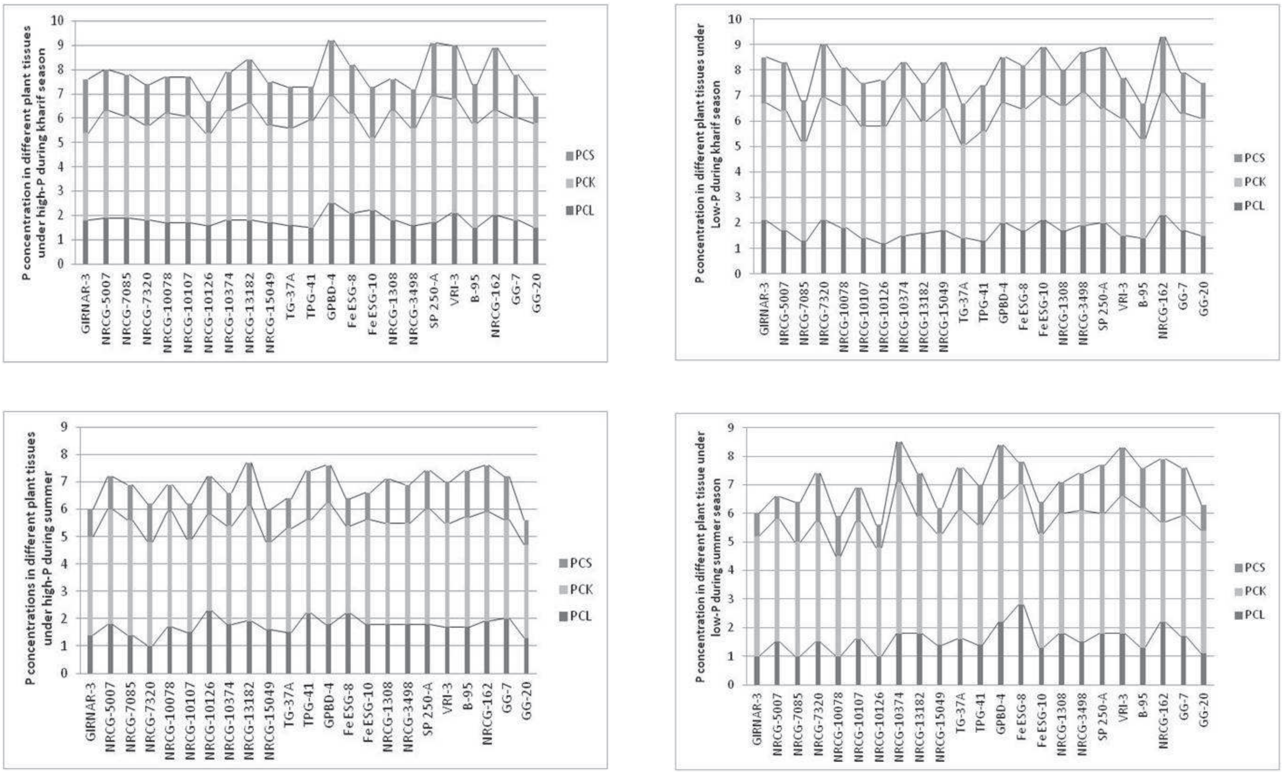

Fig. 2. P concentrations in different plant tissues

under HP and LP, respectively during *kharif*, and 1.3mg/g at both HP and LP (Table 1) during summer season. Both of these indicated slightly higher PC_L in *kharif* than summer season (Table 1). This was mainly due to high yield and hence dilution of P during summer season. Interestingly, PC_L was high in GPBD-4, NRCG-162, and NRCG-10374 and low in TG-37A, TPG-41, GG-20, NRCG-10126 and NRCG-7085 under both LP and HP conditions during both the seasons (Fig. 2). Reduction in PC_L was highest in NRCG-7085 and NRCG-10126 during *kharif* and summer seasons, respectively (Fig. 3). The genotypes NRCG-7320 and NRCG-162 had high PC_S in *kharif* and summer seasons respectively (Fig. 2).

The mean PC_K was 4.2 and 4.6mg/g under HP and LP during *kharif*, respectively and 3.8 and 4.2mg/g, respectively during summer season and significantly high under LP than HP conditions (Table 1). Genotypes NRCG-10374 and NRCG-3498 had high PC_K in both the seasons (Fig. 2) and interestingly FeESG-10 and NRCG-10374 showed increase in PC_K under LP during *kharif* and summer, respectively (Fig. 3). High-P requirement of grains demands application of more P, hence developing varieties with low grain P requirement will reduce the P requirement and improve PUE without affecting yield (Manschadi et al. 2014). In the present study genotypes GG-7, NRCG-15049, NRCG-10107 and NRCG-10126 had low PC_K.

The kernel P-uptake (P_K) was 12.8 and 9.4 mg/plant under HP and LP, respectively during *kharif*, but 43.2 and 35.6 mg/plant, respectively during summer season with a reduction of 24% and 14% under LP during *kharif* and summer seasons, respectively. The P_K under HP was significantly higher than that at LP (Table 1, Fig. 1). But, interestingly genotypes FeESG-10 and NRCG-10126 grew well under LP with less reduction in P_K during *kharif* and summer seasons, respectively (Fig. 3). Genotypes SP-250A, B-95, FeESG-8, TG-37A, NRCG-13182 and NRCG-10078 had high P_K (Fig. 1) and were identified as P-efficient and genotypes NRCG-3498, NRCG-162 and NRCG-7085 with low P_K were P-inefficient.

P efficiency indices

There were significant genotypic differences for PUE, PRE and PSF (Table 2). The P efficiency index (PEI) ranged from -2.16 (NRCG-162) to 1.54 (GG-7) during *kharif* and -1.86 (NRCG-1308) to 2.41 (NRCG-10078) during summer season. The PUE, which indicates yield produced per unit phosphorus applied, was high during summer season due to high productivity and genotype GG-7 and NRCG-10078 showed highest PUE during

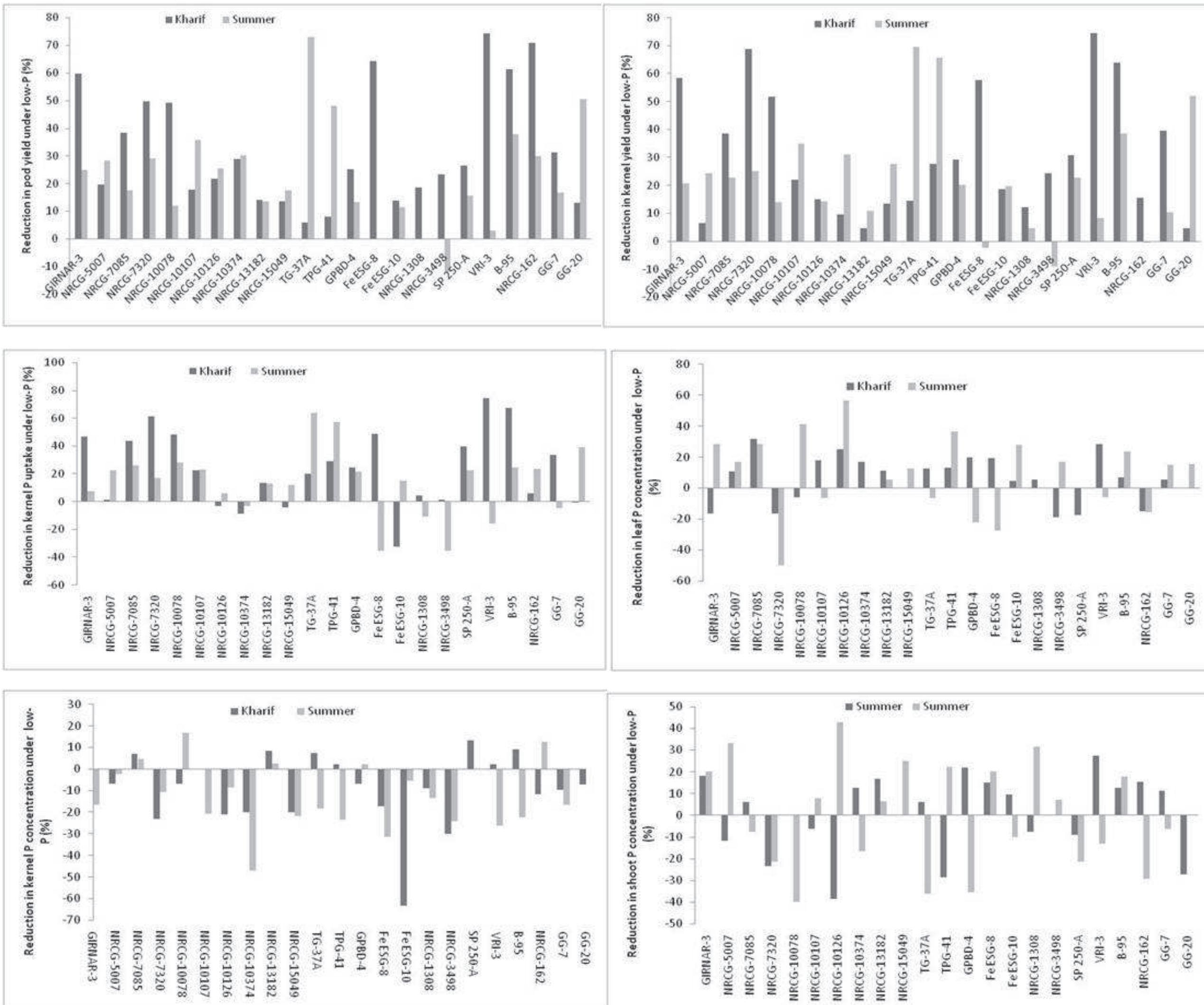

Fig. 3. Percent decrease for different traits under LP during *kharif* and summer seasons

kharif and summer seasons, respectively which is in agreement with our earlier work (Ajay et al. 2013). On the other hand the PSF was high during *kharif* season and genotypes VRI-3 and TG-37A had high PSF during *kharif* and summer seasons, respectively. The PRE was high during summer and genotypes VRI-3 and TG-37A had high PRE during *kharif* and summer seasons, respectively. Ideally P-efficient genotypes should have high yield under LP, yield of LP on par with HP (Gill et al. 2004), high PUE (Pan et al. 2008) and high PRE (Pang et al. 2010).

Genotype-by-trait biplot (GT-biplot)

GT-biplot drawn using components 1 and 2 of PCA explained 47% variation (Fig. 4). The relatively low proportion of variation reflects the complexity of relationships and still captures fundamental pattern among the traits (Yan and Rajcan 2002). The PY, KY and P_K with long vectors explained largest variation whereas PC_L, PC_S and PC_K with short vector length explained less variation. Most prominent relations revealed by GT-biplots are 1) strong positive association among PY, KY and P_K under LP and HP; 2) strong positive associations among PC_L, PC_S and PC_K under LP and HP in both the seasons. Genotypes NRCG-13182 during *kharif* and NRCG-10078, SP-250A and FeESG-10 during summer season were better for PY, KY and P_K; genotypes NRCG-162 and GPBD-4 had relatively higher PC_L and PC_S. The P-efficient (FeESG-10, GG-7, GG-20 and TG-37A) and P-inefficient (NRCG-162, GPBD-4, NRCG-7320 and NRCG-7085) genotypes identified in the present study could be used for cultivation in P-deficit soils, and in genetic studies to identify QTLs or genes associated with PUE.

Table 2. P efficiency indices of peanut genotypes

	PEI		PUE		PRE		PSF	
	Kharif	Summer	*Kharif*	Summer	*Kharif*	Summer	*Kharif*	Summer
GIRNAR-3	1.25(E)	–0.37(ME)	42.3(E)	111.3(ME)	24.8(E)	23.2(ME)	0.59(I)	0.21(ME)
NRCG-5007	–0.69(ME)	–0.50(ME)	23.7(ME)	99.3(ME)	1.6(ME)	24.4(ME)	0.07(E)	0.25(ME)
NRCG-7085	–1.52(I)	–0.91(ME)	16.3(I)	85.2(ME)	6.3(ME)	19.4(ME)	0.39(ME)	0.23(ME)
NRCG-7320	–0.39(ME)	–1.53(I)	26.0(ME)	74.8(I)	17.9(ME)	18.9(ME)	0.69(I)	0.25(ME)
NRCG-10078	0.15(ME)	2.41(E)	32.1(ME)	164.5(E)	16.6(ME)	23.1(ME)	0.52(ME)	0.14(ME)
NRCG-10107	–0.45(ME)	0.23(ME)	26.9(ME)	131.5(ME)	5.9(ME)	46.2(ME)	0.22(ME)	0.35(ME)
NRCG-10126	0.59(ME)	–1.46(I)	37.8(ME)	79.2(I)	5.7(ME)	11.4(ME)	0.15(ME)	0.14(ME)
NRCG-10374	–0.12(ME)	–0.49(ME)	30.7(ME)	108.2(ME)	2.9(ME)	33.6(ME)	0.10(ME)	0.31(ME)
NRCG-13182	0.46(ME)	–0.01(ME)	36.9(ME)	109.0(ME)	1.8(ME)	11.9(ME)	0.05(E)	0.11(ME)
NRCG-15049	–0.85(ME)	0.56(ME)	22.7(ME)	150.2(E)	3.1(ME)	41.9(ME)	0.14(ME)	0.28(ME)
TG-37A	0.46(ME)	1.11(E)	36.7(ME)	162.3(E)	5.3(ME)	112.9(E)	0.15(ME)	0.70(I)
TPG-41	–0.24(ME)	0.70(ME)	30.5(ME)	152.5(E)	8.4(ME)	100.3(E)	0.28(ME)	0.66(I)
GPBD-4	–1.79(I)	0.01(ME)	11.7(I)	106.7(ME)	3.4(ME)	21.8(ME)	0.29(ME)	0.20(ME)
FeESG-8	0.22(ME)	–0.32(ME)	32.5(ME)	122.1(ME)	18.8(ME)	-2.6(I)	0.60(I)	-0.02(E)
FeESG-10	1.02(E)	1.26(E)	38.7(ME)	155.2(E)	7.2(ME)	30.7(ME)	0.19(ME)	0.20(ME)
NRCG-1308	0.32(ME)	–1.86(I)	35.6(ME)	55.7(I)	4.4(ME)	2.6(ME)	0.12(ME)	0.05(ME)
NRCG-3498	–0.71(ME)	–0.99(ME)	23.1(ME)	81.4(I)	5.6(ME)	-7.3(I)	0.25(ME)	–0.09(E)
SP250-A	0.78(ME)	1.70(E)	36.9(ME)	143.1(ME)	11.4(ME)	32.7(ME)	0.31(ME)	0.23(ME)
VRI-3	1.46(E)	–0.12(ME)	46.0(E)	111.5(ME)	34.3(E)	9.3(ME)	0.75(I)	0.08(ME)
B-95	0.78(ME)	1.97(E)	39.3(ME)	168.0(E)	25.2(E)	64.8(E)	0.64(I)	0.39(ME)
NRCG-162	–2.16(I)	-1.45(I)	5.3(I)	68.0(I)	0.8(I)	-0.2(I)	0.16(ME)	–0.01(E)
GG-7	1.54(E)	–0.08(ME)	46.6(E)	104.6(ME)	18.5(ME)	10.8(ME)	0.40(ME)	0.10(ME)
GG-20	–0.08(ME)	0.14(ME)	32.3(ME)	137.9(ME)	1.5(ME)	71.9(ME)	0.05(E)	0.52(I)

E=P-efficient; ME=moderately P-efficient; I=P-inefficient; PEI=Phosphorus Efficiency Index; PUE=Phosphorus use efficiency under HP; PRE=P response efficiency; PSF=P stress factor

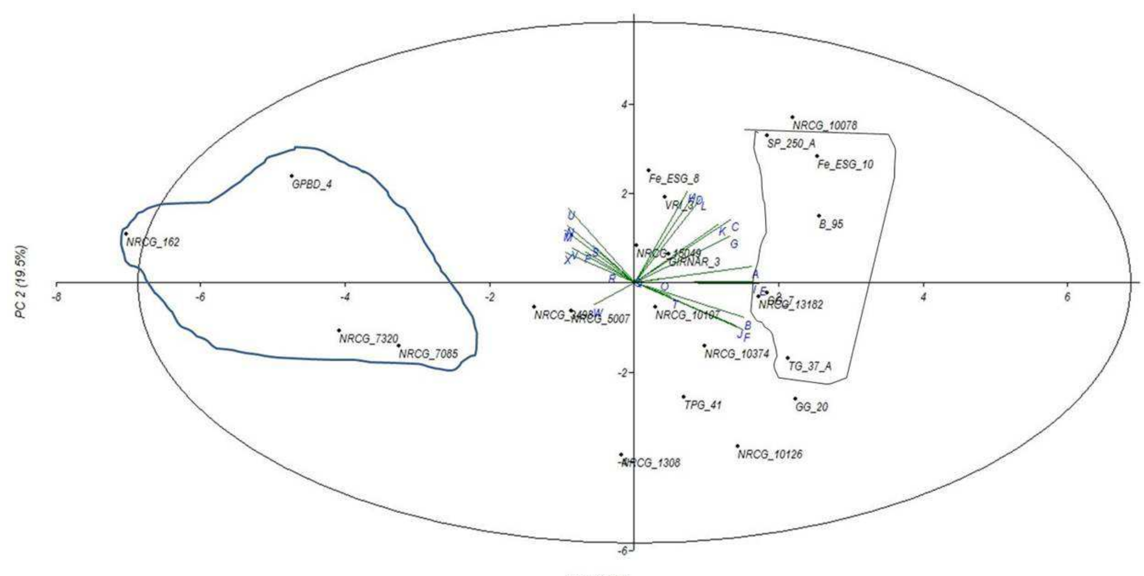

Fig. 4. Genotype-trait (GT) biplot showing the distribution of 23 peanut genotypes. A=PY-HP$_{kharif}$; B=PY-LP$_{kharif}$; C=PY-HP$_{summer}$; D=PY-LP$_{summer}$; E=KY-HP$_{kharif}$; F=KY-LP$_{kharif}$; G=KY-HP$_{summer}$; H=KY-LP$_{summer}$; I=P$_K$-HP$_{kharif}$; J=P$_K$-LP$_{kharif}$; K=P$_K$-HP$_{summer}$; L=P$_K$-LP$_{summer}$; M=PC$_L$-HP$_{kharif}$; N=PC$_L$-LP$_{kharif}$; O=PC$_L$-HP$_{summer}$; P=PC$_L$-LP$_{summer}$; Q=PC$_K$-HP$_{kharif}$; R=PC$_K$-LP$_{kharif}$; S=PC$_K$-HP$_{summer}$; T=PC$_K$-LP$_{summer}$; U=PC$_S$-HP$_{kharif}$; V=PC$_S$-LP$_{kharif}$; W=PC$_S$-HP$_{summer}$; X=PC$_S$-LP$_{summer}$

Authors' contribution

Conceptualization of research (ABC, SKB, ALS); Designing of the experiments (ABC, NK, HCD); Contribution of experimental materials (ABC, ALS); Execution of field/lab experiments and data collection (HNM, ADM, MCD); Analysis of data and interpretation (HNM, ABC, NK); Preparation of manuscript (ABC, SKB, ALS).

Declaration

The authors declare no conflict of interest.

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