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VARIATION IN PHOSPHORUS ACQUISITION EFFICIENCY AND OTHER CHARACTERS OF CHICKPEA GENOTYPES GROWN IN PHOSPHORUS DEFICIENT SOIL

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is the third important pulse crop in the world after beans and peas. Low availability of phosphorus (P) is a major abiotic constraint in chickpea crop. Thus, the present study conducted to identify high P-acquisition efficient chickpea genotypes in P-deficit region. The screening was conducted with 104 diverse chickpea genotypes at two locations characterized by P-sufficient and deficient conditions. Seed yield (g/ plant), shoot phosphorus concentration (%) and the components traits recoded significant variability among the genotypes. Shoot phosphorus accumulation showed significant positive response to seed yield. The genotypes had low shoot phosphorus concentration and seed yield per plant (g) in low phosphorus condition compared with high phosphorus condition. The genotype IPC-2011-70 had maximum phosphorus acquisition efficiency and DCP-92-3 had low phosphorus acquisition efficiency in both the locations compare to other chickpea genotypes. The first four principal components contributed about 78.70 % towards the total variability. The bi-plot analysis results revealed that the positive associations of shoot phosphorus concentration and seed yield per plant, seed yield per hectare, number of pods per plant, number of primary branches, number secondary branches, plant biomass and harvest index.

Key words : Chickpea, Phosphorus acquisition efficiency, Phosphorus deficient soils, Plant Biomass, Seed yield.

Introduction

Chickpea (*Cicer arietinum* L.) is the 2nd most important grain legume after common been and 3rd important pulse crop widely cultivated in semi-arid region (Jukanti *et al*., 2012). It is cultivated in almost all parts of the world, about 19 countries have more than 20,000-hectare area. India, Turkey, Pakistan, Iran, Australia, Mexico, Ethiopia, Myanmar, Spain and Bangladesh are the major chickpea producing countries contributing 96 per cent of global production. India is the largest producer of chickpea accounting for 73.46 per cent of global production and area with 13.75 million tonnes production from 10.91 million-hectare area and productivity of 12.6 q/ha during 2021-22 (4th estimate) (DES 2023, MOAF&W, GoI). Due to possession of 20-30% protein, 40% carbohydrate along with essential macro and micronutrient and having less anti-nutritional factors, this legume is considered as functional food or nutraceutical for the resource poor vulnerable sector of the developing World (McIntosh and Topping, 2000; Charles *et al*., 2002). Moreover, being a leguminous crop, it has the capability of symbiotic nitrogen fixation, which making this crop as a useful component of cropping system for sustaining soil health and reducing cost of cultivation of succeeding crops. Despite of having immense potential, the productivity of this legume is stagnant due to poor technological intercession, and array of biotic and abiotic stresses. Additionally, narrow genetic base due to domestication from a single progenitor, *C. reticulatum* further impede genetic improvement of this crop (Abbo *et al*., 2003; Varshney *et al*., 2010). This creates exigency of breeding intervention for improving yield status through identification, utilization and development of cultivars tolerant to key biotic and abiotic stresses.

Among the crucial macronutrients that plants require for their growth and development is phosphorus. It's important in is nucleic acid synthesis, membrane build-up and stability, energy metabolism and many other critical physiological and biological processes during plant growth and development (Lambers *et al*., 2015). Legumes generally crave more P than non-legumes, as because, N_2-fixing root nodules are strong P sinks (Sprent, 1999). The main concern regarding phosphorus nutrition is in the fact that in spite of their abundance in soil, it is poorly available to plants due to its extremely low diffusion rate (Shen *et al*., 2011) and substantial fixation by soil minerals which rises aquestion of uselessness in soil. Phosphorus fixation is the sorption and precipitation of inorganic phosphorus to produce less soluble compounds. In acid soils, H_2PO^{-4} reacts with insoluble oxides of iron, aluminum and manganese. In alkaline soils, soluble H_2PO^{-4} quickly reacts with calcium to form insoluble compounds. These compounds are sparingly soluble and couldn't provide the phosphorus in plant available form both in sufficient amount and in needed time. Phosphorus deficiency can be overcome by the application of Phosphorus fertilizers, however, the excessive use of chemical fertilizers may have serious environmental consequences, including the contamination of soil and water resources. Additionally, the global demand for use of Phosphorus fertilizers are projected to increase significantly with the explosive growth of the global population. Thus, it has been predicted that global Phosphorus reserves will be depleted within next 100 years or even earlier. Sustainable management of phosphorus in agriculture requires that plant biologists should discover mechanisms that will enhance phosphorus acquisition and exploit these adaptations to make plants more efficient at acquiring phosphorus, develop phosphorus efficient germplasm, and advance crop management technologies that will increase soil phosphorus availability (Carroll *et al*., 2003). Thus, limitation of grain crop productivity by phosphorus (P) is a widely accepted phenomenon and will probably increase in the future. Enhanced P efficiency can be achieved by improved uptake of phosphate from soil (P-acquisition efficiency) and by improved productivity per unit P taken up (P-use efficiency). There is substantial genetic variation in various traits associated with phosphorus uptake efficiency within the crop plants has been reported by Veneklaas *et al*. (2012). Analysis of this variation may help to the identification of efficient genotypes with higher P-acquisition efficiency and genetic loci that influence it. Thus, improvements in phosphorus uptake efficiency may be acquired through selection of efficient genotypes and further breeding through a combination of different approaches.

Like other crops, yield of chickpea also suffers in problem soil where the available phosphorus is low. In West Bengal, average chickpea productivity is comparatively higher than national average. But, in areas where soil is acidic and phosphorus availability is low, reduced crop growth as well as yield is noticed. Significant response to application of phosphorus was observed in chickpea in red and laterite region of West Bengal (Dutta and Pandyopadhyay, 2009), where the soil is acidic and P availability is low. Thus, the present study was undertaken to identify the high phosphorus acquisition efficient chickpea genotypes from 104 chickpea genotypes and the characters associated with it.

Materials and Methods

Plant material and experimental design

One hundred and four chickpea genotypes (Table 1) were collected from International Center for Agriculture Research in the Dry Areas (ICARDA) and All India Coordinated Research Project on Chickpea (AICRP on Chickpea), Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal, India. The experiments (Sekhampur and Kalyani) were laid out in *Augmented Randomized Complete Block Design* (ARCBD) (Federer, 1956). Every genotype in each block was grown in 2 rows of 2.5meter length with a spacing of 30 cm between rows and 10 cm between plants.

Experimental site

The field experiment was conducted in two different soils *viz*., red and lateritic soil (Sekhampur) and new alluvial soil (Kalyani).

Red and lateritic soil (Sekhampur)

Filed experiment was conducted at the Regional Research Sub Station (RRSS) of Bidhan Chandra Krishi Viswavidyalaya, Sekhampur, Birbhum, West Bengal (Red & Lateritic Zone) during *rabi* season of 2015-2016 and 2016-2017 and this site was situated at 23^{o}.55' N latitude and 87^{0}.32'E longitude with an average altitude of 11.5 meters above mean sea level.

New alluvial soil (Kalyani)

Another field experiment was conducted at new alluvial soil at the District Seed Farm, 'AB' block, Kalyani, Nadia (NAZ) during *rabi* season of 2015-2016 and 2016-2017 and this site was situated at 23^{0}.50'N latitude and 89^{0}.00 E longitude with an average altitude of 9.75 meters above mean sea level.

Table 1 : List of chickpea genotypes used in the experiment.

S. no.	Name of the Genotype	Type	S. no.	Name of the Genotype	Type	S. no.	Name of the Genotype	Type
1	AGBL – 110	*Desi*	37	IPC -2010-25	*Desi*	73	ICCV -13111	*Desi*
2	AGBL - 122	*Desi*	38	IPC -2010-37	*Desi*	74	ICCV -13116	*Desi*
3	AGBL - 134	*Desi*	39	IPC -2008-89	*Desi*	75	ICCV -13117	*Desi*
4	AGBL – 146	*Desi*	40	IPC -2010-219	*Desi*	76	ICCV -13118	*Desi*
5	AGBL - 158	*Desi*	41	IPC -2011-69	*Desi*	77	ICCV -13305	*Kabuli*
6	AGBL - 160	*Desi*	42	IPC -2011-141	*Desi*	78	ICCV -13306	*Kabuli*
7	AGBL – 172	*Desi*	43	IPC -2011-70	*Desi*	79	ICCV -13307	*Kabuli*
8	AGBL – 184	*Desi*	44	IPC -2011-64	*Desi*	80	ICCV -13308	*Kabuli*
9	GJG – 0814	*Desi*	45	IPC -2011-123	*Desi*	81	ICCV -13309	*Kabuli*
10	GJG – 0904	*Desi*	46	IPC -2010-94	*Desi*	82	ICCV -13311	*Kabuli*
11	GJG – 0919	*Desi*	47	FLIP – 07 -255C	*Kabuli*	83	ICCV -13312	*Kabuli*
12	GAG – 1107	*Desi*	48	FLIP – 07 -218C	*Kabuli*	84	ICCV -13314	*Kabuli*
13	GAG – 1111	*Desi*	49	FLIP – 06 -40C	*Kabuli*	85	ICCV -13316	*Kabuli*
14	GJG – 1211	*Desi*	50	FLIP – 07 -266C	*Kabuli*	86	ICCV -13317	*Kabuli*
15	GJG – 1304	*Desi*	51	FLIP – 07 -36C	*Kabuli*	87	ICCV -13318	*Kabuli*
16	GJG – 1311	*Desi*	52	FLIP – 07 -249C	*Kabuli*	88	ICCV -14103	*Desi*
17	24001-4-3	*Desi*	53	FLIP – 01 -29C	*Kabuli*	89	ICCV -14106	*Desi*
18	24002-4-3	*Desi*	54	FLIP – 07 -127C	*Kabuli*	90	ICCV -14107	*Desi*
19	24003-1-1	*Desi*	55	FLIP – 07 -3C	*Kabuli*	91	ICCV -14108	*Desi*
20	24003-2-1	*Desi*	56	FLIP – 07 -176C	*Kabuli*	92	ICCV -14112	*Desi*
21	24004-3-1	*Desi*	57	ICC -7441	*Desi*	93	ICCV -14118	*Desi*
22	24005-3-1	*Desi*	58	ICC -8621	*Desi*	94	JG – 16 (CH)	*Desi*
23	24006-2-1	*Desi*	59	ICC -4958	*Desi*	95	GG – 1 (CH)	*Desi*
24	24007-5-1	*Desi*	60	ICC -15618	*Desi*	96	GG – 4 (CH)	*Desi*
25	24015-2-1	*Desi*	61	ICC -16207	*Desi*	97	RSG – 888	*Desi*
26	24015-4-1	*Desi*	62	ICC -3325	*Desi*	98	DCP – 92 – 3	*Desi*
27	24017-1-1	*Desi*	63	ICC -15868	*Desi*	99	JG – 11	*Desi*
28	24017-2-1	*Desi*	64	ICC -1098	*Desi*	100	VIHAR	*Kabuli*
29	24018-2-1	*Desi*	65	ICCV -13101	*Desi*	101	ANURADHA	*Desi*
30	24031-1-1	*Desi*	66	ICCV -13102	*Desi*	102	JG-14,	*Desi*
31	24031-3-1	*Desi*	67	ICCV -13103	*Desi*	103	KWR-108	*Desi*
32	24032-2-1	*Desi*	68	ICCV -13104	*Desi*	104	BG 256	*Desi*
33	24034-4-1	*Desi*	69	ICCV -13105	*Desi*			
34	24042-1-1	*Desi*	70	ICCV -13106	*Desi*			
35	24042-5-1	*Desi*	71	ICCV -13107	*Desi*			
36	24043-4-1	*Desi*	72	ICCV -13109	*Desi*			

Season

The climatic condition of above mentioned regions is sub-tropical humid and the entire year can be classified into three distinct seasons, *viz.,* winter season which is short and mild, starting from month of November which extends up to middle of February, summer seasons which begins in the month of March to end of May and sometime extended up to June and rainy seasons which starts in the month of June and ends in the September and sometime extended up to middle of October. In these regions, neither summer temperature is too high nor is the winter too cold. So, this zone falls under the sub-tropical humid climate where summer and winter both are short and mild.

Soil characteristics of the experimental fields

Red and lateritic soil (Sekhampur)

The soil of the red and laterite zone has been developed from old alluvium and laterite mass which is sandy- clay loam in texture. It is having low water holding capacity (WHC), low fertility status and acidic in reaction. This soil, prior to the start of this study had the following properties, pH 5.38, organic carbon 0.49 per cent, available nitrogen 176.5 kg per ha, available phosphorus 9.4 and available potassium 188.1 kg per ha. The recommended agronomical and plant protection practices were adopted for better crop growth but phosphorus fertilizer was not applied in this Farm. Earlier to the chick pea sowing, Rice crop was grown in the fields.

New alluvial soil (Kalyani)

The soil of the new alluvial zone of experimental field was alluvial and sandy loam in texture having good water holding capacity (WHC), medium fertility status and neutral in reaction. This soil is classified as clay loam and the soil properties at the start of this study were neutral in reaction having pH 7.56, organic carbon 0.55 per cent, available nitrogen 198.7 kg, available phosphorus 13.5 and available potassium 115.3 kg per ha. The recommended agronomical and plant protection practices were adopted for better crop growth. Earlier to the chick pea sowing, Rice crop was grown in the fields.

Estimation of shoot phosphorus concentration

For estimating the shoot phosphorus concentration (g/kg), Vanado-molybdate yellow-colour method (Jackson, 1973) was followed. Plant samples were collected from both the locations at pre-flowering stage (45 days after sowing) and collected plant samples were drying in hot air oven for 48 hours maintaining at 72^0C. About 0.5 gm of the dried plant tissue was weighed accurately in a digestion tube. Digestion of plant material was done by adding triple acid mixture and kept overnight. Triple acid mixture is made of concentrated nitric acid, perchloric acid and sulphuric acid in the ratio 9:4:1. After the precold digestion, the digestion mixture was heated at 180 to 200°C for 2 hrs or till the digestion mixture becomes a clear solution. The digest was made up to 50 ml. Then 5 ml of digest was taken in a standard flask and 5 ml of Vanadomolybdate reagent was added. The volume was made to 25 ml with distilled water. The yellow colour developed was noted after10 minutes at 490 nm in a spectrophotometer. Standard graph was prepared and calculated accordingly.

Statistical analysis

Observations were recorded as per the DUS guidelines of chickpea, on the basis of five randomly selected plants in each genotype for various yield and yield attributing traits. In the present study, mean, principle component analysis (PCA) and linear regression analysis were calculated to find out genetic variation between the chickpea genotypes. Significant differences among the genotypes were tested by Duncan's Multiple Range Test (Duncan, 1955) at 5% level. The statistical analysis was performed by using MS EXCEL, Statistical Tool for Agricultural Research (STAR) and R software.

Results and Discussion

Significant genetic variation existed in seed yield per plant among the 104 chickpea genotypes in both the field experiments and which provide a potential for assessment P-efficient chickpea genotypes. These results supported with previous research scientists, they reported that the P-efficient plant genotypes demonstrated greater yield compared to the P-inefficient when grown in low P condition in Soya bean (Zhou *et al*., 2016 and Pan *et al*., 2008).

Average seed yield (g $plant^1$) in Kalyani ranged from 1.57 g to 12.90 g with a mean of 6.37 g and in Sekhampur it ranged from 1.30 g to 12.87 g with a mean of 5.54 g. The mean value of shoot phosphorus concentration in Kalyani ranged from 0.09% to 0.39% with a mean of 0.26% and in Sekhampur it ranged from 0.07% to 0.19% with a mean of 0.22%. Shoot phosphorus accumulation showed significant response to yield. Moreover, the linear-model described the positive relationship between seed yield plant and shoot phosphorus concentration (Fig. 1). Shoot phosphorus concentration and seed yield per plant were divided into two groups-below or above the mean line. We delimit the phosphorus efficient genotypes with high yield and high shoot phosphorus concentration. On the contrary, the P-inefficient genotypes may be with low yield and low shoot phosphorus concentration. There are 31 and 32 genotypes with high (above the mean line) seed yield and shoot phosphorus concentration in Kalyani and Sekhampur, respectively. On the contrary, 29 and 31 genotypes possessed low (below the mean line) seed yield and low shoot phosphorus concentration in Kalyani and Sekhampur, respectively. The genotypes GJG-1311 and ICCV-13306 had high shoot phosphorus concentration but they were poor yielders. On the contrary, the genotypes AGBL-160 and ICCV-13305 had high mean yield but they were less efficient in phosphorus acquisition from the soil (Figs. 2 and 3).

Top 15 and last 15 genotypes in respect of seed yield are given in Tables 2 and 3, respectively. Out of the top 15 genotypes 7 genotypes *viz*., AGBL-184, ICCV-13318, ICCV-13105, UPC-2011-123, IPC-2011-70, JG-11 and ICCV-13117 had higher shoot phosphorus concentration and high harvest index (Table 2). Out of the last 15 genotypes 5 genotypes *viz*., FLIP-07-249C, ICC-16207,

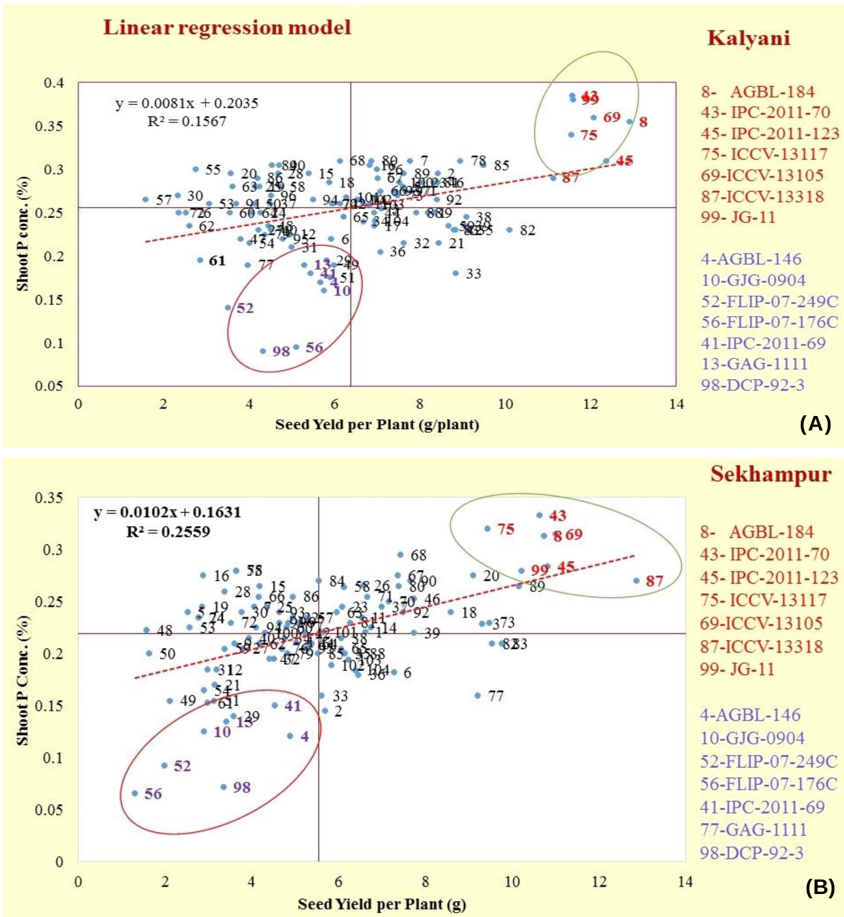

Fig. 1 : Relationship between seed yield per plant and shoot P content, **A)** Kalyani location and **B)**. Sekhampur location. Red colour number genotypes are phosphorus acquisition efficient genotypes and purple colour genotypes are phosphorus acquisition inefficient genotypes.

FLIP-07-176C, FLIP-07-127C and DCP-92-3 had low shoot phosphorus concentration and two genotypes *viz.*, FLIP-07-249C and DCP-92-3 had low plant biomass. (Table 3). From the first experiment, we selected 14 genotypes (7 high and 7 low) based on the seed yield per plant and P acquisition efficiency. These genotypes recorded similar performance in the both the locations. IPC-2011-70, AGBL-184, ICCV-13318, ICCV-13117, ICCV-13105, IPC-2011-123, JG-11 were chosen to represent the P-efficient genotypes and DCP-92-3, FLIP-07-176, AGBL-146, FLIP-07-249C, GAG-1111, IPC-2011-69, GJG-0904 were chosen to represent the P-inefficient genotypes.

The mean value of shoot phosphorus concentration and other agro-morphological traits were reduced in Sekhampur location compared to Kalyani location (Tables 4 and 5). However, phosphorus efficient chickpea genotypes had high phosphorus acquisition efficiency with high seed yield per plant than phosphorus inefficient genotypes in low and high phosphorus condition. P-efficient chickpea genotypes are able to obtain

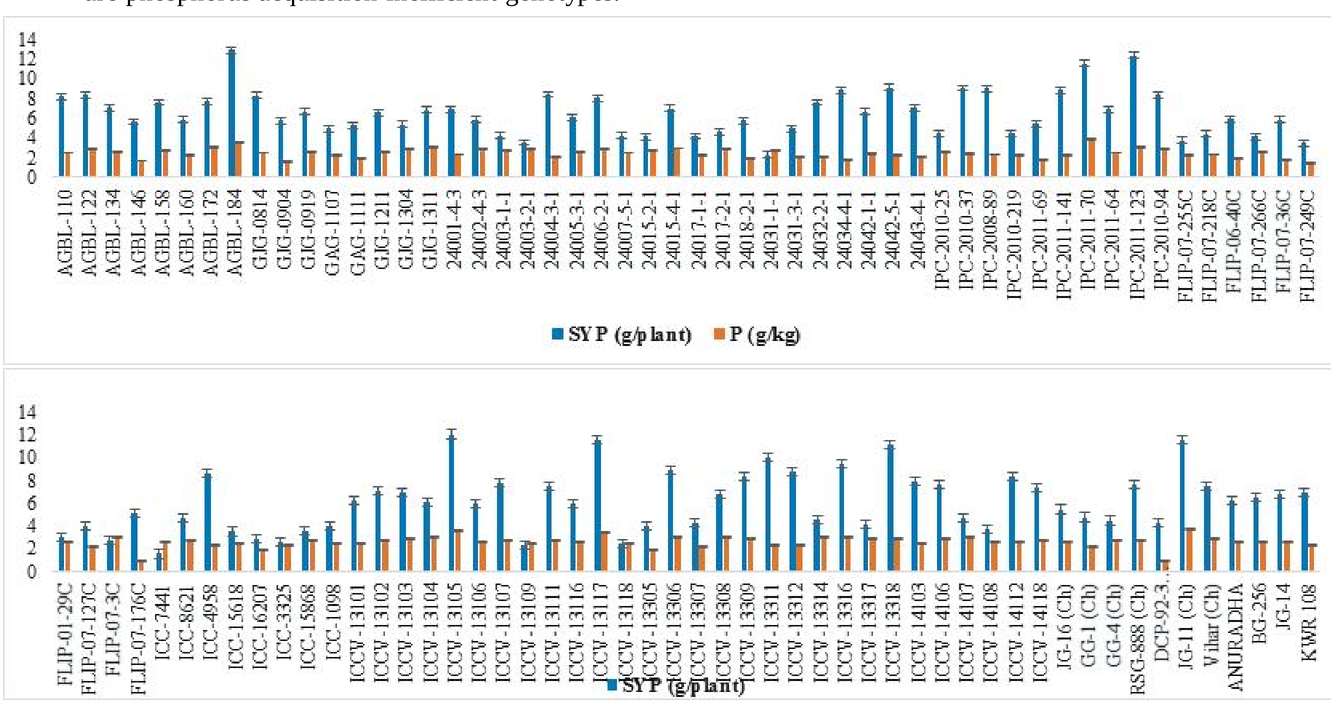

Fig. 2 : Shoot phosphorus concentration (g/kg) and seed yield per plant (g) of 104 chickpea genotypes under P deficient condition (Sekhampur).

Table 2 : Top 15 chickpea genotypes in seed yield per plant among 104 genotypes, with some genotypes also being in the top 15 for shoot phosphorus concentration, plant biomass, harvest index and number of pods per plant as shown by black stars.

S. no.	Entry name	SYP	P	PB	HI	NPP
1	AGBL-184	*	*	*	*	
2	ICCV-13318	*	*	*	*	
3	ICCV-13105	*	*		*	*
4	IPC-2011-123	*	*		*	*
5	IPC-2011-70	*	*	*	*	*
6	JG-11	*	*		*	*
7	ICCV-13117	*	*		*	*
8	ICCV-13311	*			*	
9	ICCV-13312	*			*	
10	ICCV-14106	*				*
11	AGBL-134	*		*		*
12	ICCV-13111	*				*
13	IPC-2008-89	*				
14	IPC-2010-94	*			*	
15	AGBL-110	*				

SYP-Seed yield per plant(g), P- Shoot phosphorus concentration (%), PB-Plant biomass (g), HI-Harvest Index and NPP-Number of pods per plant

Table 3 : Last 15 chickpea genotypes in seed yield per plant among 104 genotypes, with some genotypes also being in the last 15 for shoot phosphorus concentration, plant biomass, harvest index and number of pods per plant as shown by black stars.

S. no.	Entry name	SYP	P	PB	HI	NPP
1	FLIP-07-249C	*	*	*	*	*
2	FLIP-01-29C	*			*	*
3	FLIP-07-266C	*			*	*
4	ICC-16207	*	*		*	
5	ICCV-13109	*			*	*
6	FLIP-07-218C	*			*	*
7	24031-1-1	*			*	
8	FLIP-07-3C	*			*	*
9	FLIP-07-176C	*	*		*	*
10	ICC-3325	*			*	
11	ICC-7441	*			*	
12	FLIP-07-127C	*	*		*	*
13	DCP-92-3	*	*	*		
14	ICCV-13118	*			*	
15	24007-5-1	*				

SYP-Seed yield per plant(g), P- Shoot phosphorus concentration (%), PB-Plant biomass (g), HI-Harvest Index and NPP-Number of pods per plant.

Table 4 : Mean performance of selected 7 high and 7 low phosphorus acquisition efficient genotypes in Kalyani.

S. no.	Genotype	DM	PH	NPP	HSW	PB	HI	P	SYP
1	IPC-2011-70	123^{e}	56.95^{cde}	53.17^{a}	18.07^{fg}	31.30^{a}	0.31^{a}	0.39^{a}	11.55^{a}
2	AGBL-184	124^{e}	70.50^{ab}	39.34^{cde}	25.44^{cd}	29.20^{ab}	0.31^{a}	0.36^{a}	12.91^{a}
3	ICCV-13318	125^{e}	66.90^{abc}	31.67^{ef}	39.21^{a}	26.95^{abc}	0.29^{a}	0.29^{ab}	11.11^{a}
4	ICCV-13117	132^{b}	55.85^{de}	42.34^{bcd}	24.79^{cde}	27.25^{abc}	0.30^{a}	0.34^{a}	11.54^{a}
5	ICCV-13105	133^{b}	61.63^{bcd}	51.34^{ab}	21.31^{ef}	29.50^{ab}	0.29^{a}	0.36^{a}	12.07^{a}
6	IPC-2011-123	123^{e}	69.10^{ab}	44.17^{abc}	28.32^{c}	26.30^{abcd}	0.32^{a}	0.31^{a}	12.37^{a}
7	JG-11	136^{a}	56.77^{cde}	46.50^{abc}	21.61^{def}	25.10^{bcde}	0.32^{a}	0.38^{a}	11.58^{a}
8	DCP-92-3	125^{e}	49.27^{e}	33.83^{def}	13.85^{h}	17.70^{g}	$0.22b^{c}$	0.09^{c}	$4.33b^{c}$
9	FLIP-07-176	136^{a}	57.59^{cde}	24.34^{fg}	28.28^{c}	21.05^{defg}	0.21^{c}	0.10^{c}	$5.10b^{c}$
10	AGBL-146	124^{e}	50.15^{e}	30.17^{ef}	17.02^{gh}	21.90^{cdefg}	0.25^{b}	0.17^{c}	5.67^{b}
11	FLIP-07-249C	137^{a}	66.00^{abcd}	15.50^{g}	32.30^{b}	18.75^{fg}	0.16^{d}	0.14^{c}	3.49^{c}
12	GAG-1111	129^{c}	47.78^{e}	25.83^{f}	19.83^{fg}	23.90^{bcdef}	0.21^{c}	$0.19b^{c}$	5.29^{b}
13	IPC-2011-69	127^{d}	74.30^{a}	26.67^{f}	20.89^{efg}	20.25^{efg}	0.23^{bc}	$0.18b^{c}$	5.44^{b}
14	GJG-0904	125^{e}	57.35^{cde}	25.00^{fg}	28.65^{bc}	23.55^{cdef}	0.23^{bc}	0.16^{c}	5.75^{b}

DM - Days to maturity, PH- Plant height (cm), NPP- Number of pods per plant, HSW -Hundred seed weight (g), PB - Plant biomass (g), HI-Harvest index, P- Shoot phosphorus concentration (%) and SYP- Seed yield per plant (g).

sufficient P from acid soil and alkaline soil under P lack conditions and other P-efficient plant species also showed positively P accumulation grown in P lack conditions, like maize (Liu *et al*., 2004), wheat (Fageria and Baligar, 1999) and rice (Mori *et al*., 2016). The genotype IPC-2011-70 had maximum phosphorus acquisition efficiency and DCP-92-3 had low phosphorus acquisition efficiency in both the locations compare to other chickpea genotypes.

Principal component analysis

The principal component analysis reduces the large set of variables to a single set thus representing the large set by exploring the total variation of the correlation

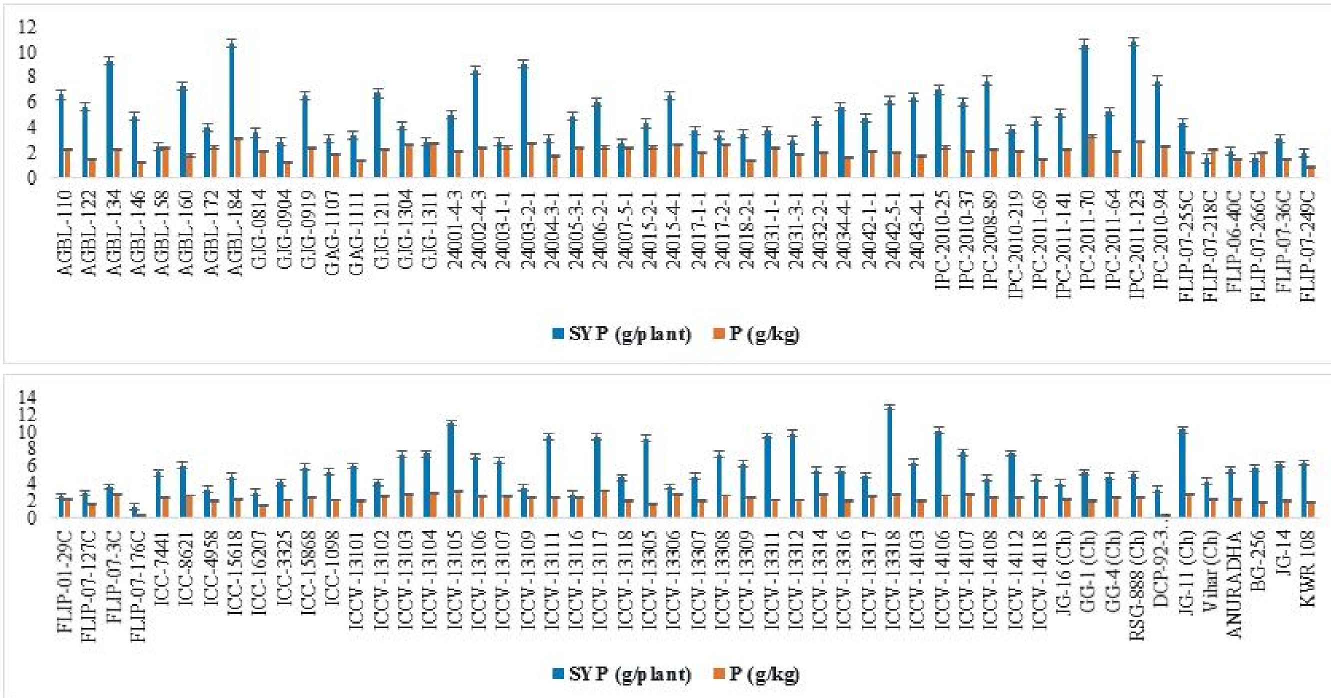

Fig. 3 : Shoot phosphorus concentration (g/kg) and seed yield per plant (g) of 104 chickpea genotypes under P sufficient condition (Kalyani).

Table 5 : Mean performance of selected 7 high and 7 low phosphorus acquisition efficient genotypes in Sekhampur

S. no.	Genotype	DM	PH	NPP	HSW	PB	HI	P	SYP
1	IPC-2011-70	123^{cd}	54.45^{abc}	50.80^{ab}	15.29^{gh}	28.10^{a}	0.24^{cd}	0.33^{a}	10.63^{ab}
2	AGBL-184	120^{d}	51.60^{abc}	38.47^{cd}	24.70^{cd}	25.05^{ab}	0.30^{bc}	0.31^{a}	10.72^{ab}
3	ICCV-13318	125^{abcd}	46.0^{5c}	34.70^{de}	34.74^{a}	23.25^{bcd}	0.37^{ab}	0.27^{a}	12.87^{a}
4	ICCV-13117	121^{d}	52.90^{abc}	57.95^{a}	23.13^{cde}	25.05^{ab}	0.31^{bc}	0.32^{a}	9.42^{b}
5	ICCV-13105	130^{a}	64.60^{ab}	49.25^{ab}	20.16^{ef}	24.85^{abc}	0.42^{a}	0.32^{a}	10.99^{ab}
6	IPC-2011-123	119^{d}	65.60^{a}	48.15^{b}	23.33^{cde}	22.75^{bcde}	0.34^{ab}	0.28^{a}	10.80^{ab}
7	JG-11	128a^{bc}	52.85^{abc}	44.40^{bc}	19.86^{ef}	21.40^{bcdef}	0.36^{ab}	0.28^{a}	10.22^{ab}
8	DCP-92-3	123^{bcd}	53.05^{abc}	29.25^{ef}	12.57^{h}	15.85^{g}	0.16^{de}	0.07^{bc}	3.34^{cde}
9	FLIP-07-176	129^{ab}	66.60^{a}	8.54^{h}	23.98^{cde}	18.35^{efg}	0.06^{f}	0.07^{c}	1.31^{e}
10	AGBL-146	121^{d}	49.40^{bc}	24.69^{f}	16.16^{fgh}	17.30^{fg}	0.18^{de}	0.12^{bc}	4.88^{c}
11	FLIP-07-249C	130^{a}	66.45^{a}	9.80^{h}	30.41^{b}	18.60^{defg}	0.10^{ef}	0.09^{bc}	1.98^{de}
12	GAG-1111	124b^{cd}	45.65^{c}	21.34^{fg}	17.75^{fg}	21.00^{bcdef}	0.13^{ef}	0.14^{bc}	3.42^{cde}
13	IPC-2011-69	121^{d}	62.35^{ab}	21.82^{ab}	20.48^{def}	18.90^{defg}	0.19^{de}	0.15^{b}	4.52^{cd}
14	GJG-0904	123^{bcd}	55.15^{abc}	14.83^{gh}	26.82^{bc}	20.20^{cdefg}	0.10^{ef}	0.13^{bc}	2.89^{cde}

DM - Days to maturity, PH- Plant height (cm), NPP- Number of pods per plant, HSW -Hundred seed weight (g),PB - Plant biomass (g), HI-Harvest index, P- Shoot phosphorus concentration (%) and SYP- Seed yield per plant (g).

coefficients as well as of error variance (Brown, 2001). The Eigen values were calculated to decide the number of factors (Gorsuch, 1983). Principal components (Eigen value greater than one), Eigen values (Latent Root), per cent variability, cumulative per cent variability and component loading of different characters are presented in Table 6. In the present study, the three principal components contributed 72.46% towards the total variability. The principal component with Eigen values less than one were considered as non-significant. It was therefore inferred that the essential features of data set had been represented in the first four principal components.

The first principal component (PC1) contributed maximum towards the total variability (39.73%) presented in Table 6. The characters *viz.*, number of primary branches (0.584), number of secondary branches (0.729), number of pods per plant (0.794) and number of seeds per pod (0.427), plant biomass (0.245), harvest index

(0.821), shoot phosphorus concentration (0.566) and seed yield per plant (0.878) were positively loaded. Days to first flowering (-0.505), days to 50 per cent flowering (-0.543), days to maturity (-0.467), plant height (-0.400), pod bearing length (-0.434) and hundred seed weight (-0.156) were negatively loaded. The second principal component (PC2) shared 19.23% contribution towards the total variability. The characters *viz.*, days to first flowering (0.495), days to 50 per cent flowering (0.511), days to maturity (0.623), plant height (0.710), pod bearing length (0.636) number of primary branches (0.524), number of secondary branches (0.316), hundred seed weight (0.438) plant biomass (0.506), harvest index (0.090 shoot phosphorus concentration (0.224) and seed yield per plant (0.364) were positively loaded. Number of pods per plant (-0.016) and number of seeds per pod (-0.382) were negatively loaded. The third principal component (PC3) shared 13.51% contribution towards the total variability. The characters *viz.*, plant height (0.238), pod bearing length (0.094), hundred seed weight (0.781), harvest index (0.368), shoot phosphorus concentration (0.151) and seed yield per plant (0.146) were positively loaded. Days to first flowering (-0.564), days to 50 per cent flowering (-0.546), days to maturity (-0.003) number of primary branches (0.067), number of secondary branches (-0.359), number of pods per plant (-0.388), number of seeds per pod (-0.499) and plant biomass (-0.394) were negatively loaded.

The characters *viz.*, seed yield per plant, harvest index, number of pods per plant, number of secondary branches per plant, number primary branches per plant, shoot phosphorus concentration and days to 50 per cent flowering significantly loaded in PC1 and contributed more towards variability. It is important for studying the variance as the relative contributions are more important than the signs (indicative of direction) in principal component analysis. Halila and Strange (1997) working on screening of *kabuli* chickpea germplasm comprising of 1915 genotypes for resistance to Fusarium wilt showed that more than 80 per cent of the variation of the resistant lines was explained by 100-seed weight and days to maturity. Upadhyaya *et al.* (2006) working on ICARDA gene bank containing 16820 accessions showed that days to 50% flowering showed the highest pooled diversity index. Toker (2004) reported that in factor-I; seed yield,

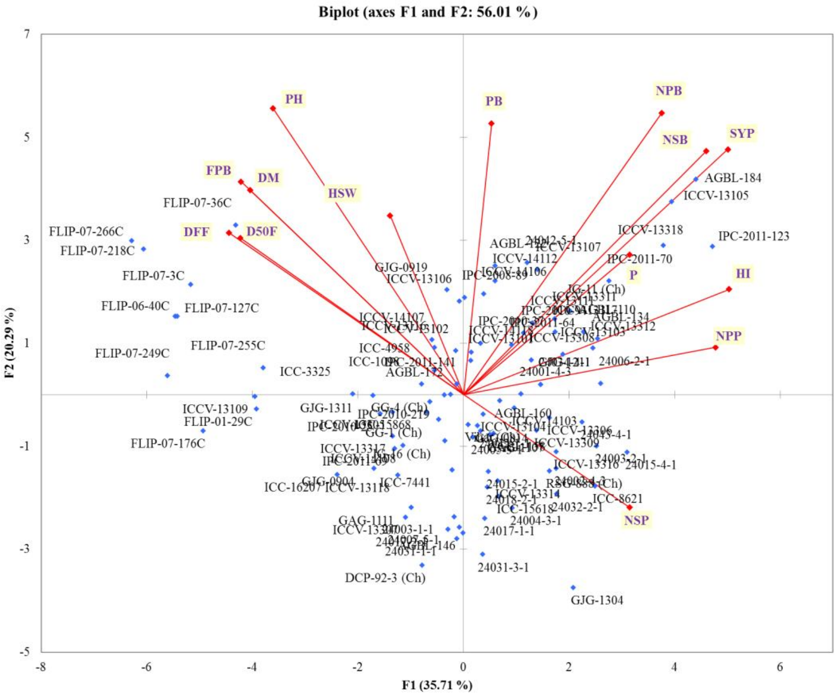

Fig. 4 : Bi-plot analysis of shoot phosphorus concentration and other agro-morphological traits in chickpea genotypes on principal component axes.

Table 6 : Eigen values, proportion of the total variance, cumulative per cent variance and component loading of different characters in chickpea.

	PC1	PC2	PC3	PC4
Eigen value	6.35	3.07	2.16	0.99
Variability (%)	39.73	19.23	13.50	6.24
Cumulative %	39.73	58.96	72.46	78.70
DFF	-0.505	0.495	-0.564	-0.292
D50F	-0.543	0.511	-0.546	-0.265
DM	-0.467	0.623	-0.003	-0.348
PH	-0.400	0.710	0.238	0.249
PBH	-0.434	0.636	0.094	0.298
NPB	0.584	0.524	-0.067	-0.124
NSB	0.729	0.316	-0.359	0.117
NPP	0.794	-0.016	-0.388	0.040
NSP	0.427	-0.382	-0.499	-0.072
HSW	-0.156	0.438	0.781	-0.134
PB	0.245	0.506	-0.394	0.459
HI	0.821	0.090	0.368	-0.349
P	0.566	0.224	0.151	0.383
SYP	0.878	0.364	0.146	-0.134

DFF- Days to first flowering, D50F- Days to 50 % flowering, DM - Days to maturity, PH- Plant height (cm), PBH- Pod bearing height (cm), NPB- Number of primary branches per plant, NSB- Number of secondary branches per plant, NPP- Number of pods per plant, NSP- Number of seeds per pod, HSW -Hundred seed weight (g), PB - Plant biomass (g), HI-Harvest index, P- Shoot phosphorus concentration (%) and SYP- Seed yield per plant (g).

biological yield, number of pods per plant, flowering duration and 100-seed weight had positive effect; while plant height, first pod height and days to flowering showed negative interrelationship.

Bi-plot analysis

The bi-plot analysis indicated positive correlation between shoot phosphorus concentration and other agro-morphological characters (Fig. 4). The bi-plot analysis results revealed that the positive associations of shoot phosphorus concentration and seed yield per plant, number of pods per plant, number of primary branches, number secondary branches, plant biomass and harvest index while plant height, pod bearing height, days to flower initiation, days to 50% flowering, days to maturity and hundred seed weight were showed negative interrelationship. These results were in conformity with Zhou *et al*. (2016), where they conducted field experiment with 274 soybean genotypes in south west of China with low soil phosphorus (P) availability. They reported that yield showed positive relationship with seed phosphorus concentration, shoot phosphorus concentration accumulation and harvest index.

Conclusion

Our results showed that significant genetic variation existed in phosphorus concentration and seed yield among the 104 genotypes grown under phosphorus sufficient (Kalyani) and deficient (Sekhampur) condition. The seven-phosphorus acquisition efficient genotypes *viz.*, IPC-2011-70, AGBL-184, ICCV-13318, ICCV-13117, ICCV-13105, IPC-2011-123, JG-11 and seven phosphorus acquisition inefficient genotypes viz., DCP-92-3, FLIP-07-176, AGBL-146, FLIP-07-249C, GAG-1111, IPC-2011-69, GJG-0904were identified in low P conditions. These fourteen genotypes used for further breeding programme to identify loci underlying low P tolerance in chickpea.

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