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Phosphorus and Micronutrient Nutrition of Chickpea Genotypes in a Multi-Nutrient-Deficient Typic Ustochrept

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ABSTRACT

The chickpea breeding program in India has not yet considered the genotypic variation in phosphorus (P) efficiency, despite the fact that the largest proportion of chickpea-growing soils are P deficient. Since general P application to chickpea is at sub-optimum levels, efficient P-utilizing genotypes will perform better than others under P-deficient conditions. High levels of P application may induce zinc (Zn) deficiency in plants grown on Zn-deficient soils. Twenty chickpea genotypes were evaluated for their P efficiency at varied levels of added P, and the effect of P levels on Zn, iron (Fe), copper (Cu), and manganese (Mn) nutrition was studied in pot-culture experiments. Three criteria were used for evaluating P efficiency; shoot dry-matter yield without P, P-uptake efficiency (PUPE), and P-utilization efficiency (PUSE). Under P-deficiency conditions (control), the genotypes BG-256, HK-94-134, Phule-G-5, and Vikash produced the highest shoot biomass. However, genotypes that were found to be superior in the absence of P did not perform in a similar way under optimum P supply. Root dry weight showed a highly significant correlation with P uptake at all P levels. In the case of PUPE, genotypes KPG-59 and Pusa-209 were found to be superior to others. With increasing P levels, PUSE declined in all the genotypes. Increasing P up to 13.5 mg kg^{-1} soil increased Zn concentration, while further increase led to decreased concentration. Genotypes KPG-59, BG-256, RSG-888, and JG-315 showed Zn concentrations below the critical limit of 20 μg Zn g^{-1} dry weight (DW) at the high level of P application (27.0 mg kg^{-1}). Iron concentration decreased with increasing P levels. Up to 13.5 mg kg^{-1} P application, Cu concentration increased and thereafter decreased. Manganese concentration gradually increased with the increasing P levels studied. Based on three criteria, BG-256 can

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be recommended for use in P-deficient conditions and can be good germplasm source material for chickpea-breeding programs for evolving P-efficient genotypes. Results also suggest that when selecting P-efficient genotypes of chickpea, it is essential to apply deficient micronutrients.

Keywords: chickpea, genotypes, micronutrients, phosphorus levels, P uptake, root growth, utilization

INTRODUCTION

Chickpea is the world's third-most-important food legume (pulse) and is consumed as a high-quality protein food. India is the world's largest producer and consumer of pulses. Among pulses, chickpea is the dominant crop, grown on an area of about 7.6 m ha in India and producing 6.2 million tons of grain. A substantial area of chickpea cultivation in India is concentrated on marginal and sub-marginal lands with limited nutrient supply. Low soil fertility, particularly phosphorus (P) deficiency, is one of the major constraints to increasing chickpea productivity (Srinivasarao et al., 2003). Out of the 135 districts covering the pulse-growing area in India, soils in 68 districts were found to be low and in another 62 districts were medium in available P status (Ghosh and Hasan, 1979). Among 3.6 million soil samples analyzed in India, 42% were found to be low in P, 38% were medium and 20% were high (Motsara, 2002). Therefore, P deficiency is the key factor for improving the grain yield of these crops. Although P recommendations have been made for chickpea-growing regions of India, farmers use varying amounts of P fertilizer on these crops (Ali et al., 2002). Under sub-optimal levels, P nutrition depends mainly on soil P source. Under these circumstances, chickpea crop suffers from P deficiency, resulting in poor yields. Some genotypes are known to mine the insoluble soil P and utilize it more efficiently, while others can better utilize applied fertilizer P (Osborne and Rengel, 2002b; Zhu et al., 2002). Selecting genotypes with high P-uptake efficiency is one of the alternative approaches for managing P-deficient soils (Graham, 1984). More efficiently utilizing cultivars reduces the costs of production and improves the value of seed and straw or residue and consequently helps to conserve the global reserves of P. Breeding for P-efficient cultivars of chickpea involves selection of genotypes or physiological investigation of genotypes, followed by their use in breeding programs. Horst et al. (1993) reported that the modern wheat (*Triticum aestivum* L.) varieties produced higher yield under P deficiency compared with the old varieties.

Breeding programs for chickpea in India have not yet considered the genotypic variation in P efficiency, despite that the largest proportion of chickpea-growing soils are P deficient. Because general P application to chickpea is at sub-optimum levels, efficient P-utilizing genotypes might perform better than others under P-deficient conditions. Although there have been several studies

on genotypic variations among other crops such as wheat (Batten and Khan, 1987; Manske et al., 2000), barley (Gahoonia and Nielsen, 1996), pigeonpea (Subbarao et al., 1997), and groundnut (Wissuwa and Ae, 1999), such studies have not been attempted in chickpea.

As for the micronutrients, deficiency of Zn is extensive, found in from 24% to 78% of Indian soils, followed by deficiency of iron (Fe) (2%–39% of soils), manganese (Mn) (2%–19% of soils), and copper (Cu) (1%–5% of soils) (Takkar, 1996). High levels of available P in soil or high application rates of phosphate are known to induce Zn deficiency in plants grown on soils with low available Zn (Gianquinto et al., 2000). The interaction of P and Zn, called P-induced Zn deficiency, has been observed in many crops (Singh et al., 1988). This effect becomes more pronounced if soils are already Zn deficient and adequate Zn is not supplied. However, the effects of P application on Zn nutrition of chickpea have not yet been studied, particularly under the conditions of deficiency of both nutrients in soil (Subbarao and Rupa, 2003).

The present study examined the P-use efficiency of 20 chickpea genotypes (now under cultivation in different regions of India) at different levels of applied P and the effect of these P levels on Zn, Fe, Cu, and Mn nutrition of chickpea on P- and Zn-deficient Typic Ustochrept soils.

MATERIALS AND METHODS

Soil Medium

Experiments were conducted in pot culture under greenhouse conditions. Bulk soil samples were collected from the New Research Farm of the Indian Institute of Pulses Research, Kanpur (lat 26° 28′N, long 80° 24′E) and processed for analysis of various physico-chemical properties. Particle-size analysis was performed using the hydrometer method following soil dispersion with Calgon (Day, 1965). Organic carbon was determined using a modified Walkley-Black procedure (Walkley and Black, 1934). Mineralizable nitrogen (N) was estimated with the alkaline permanganate method (Subbaiah and Asija, 1956). Phosphorus was extracted with sodium bicarbonate (Olsen et al., 1954) and potassium (K) with 1 *M* neutral ammonium acetate (Hanway and Heidel, 1952). Sulfur (S) was extracted with 0.01 *M* $CaCl_2$ (Williams and Steinbergs, 1959) and Zn was extracted in DTPA (Lindsay and Norvell, 1978). The physico-chemical properties and available-nutrient status of experimental soil are presented in Table 1. Soils were alkaline in reaction, low in organic carbon, low in available P, and classified as Typic Ustochrept.

Genotypes and Growth Condition

Twenty chickpea genotypes under cultivation in different regions of India, namely Phule G −5, KPG 59, Pusa 209, BG 413, BG 256, K 850, Pant G-114,

Table 1
Physico-chemical properties and available nutrient status of experimental soil

Soil properties	Value
Soil Taxonomy	Typic Ustochrept
pH (1:2.5)	7.7
Organic carbon (g kg^{-1})	2.1
$CaCO_3$ (g kg^{-1})	2.1
Clay (%)	5.5
Silt (%)	30.0
Sand (%)	64.5
Available N (mg kg^{-1})	62.50
Available P (mg kg^{-1})	1.43
Available K (mg kg^{-1})	40.2
Available S (mg kg^{-1})	3.04
Available Zn (mg kg^{-1})	0.4

SAK 1-9516, GPF 2, Vikash, Radhey, GCP 101, DCP 92-3, HK 94-134, RSG 888, GCP 105, JG 315, Vijay, GNG 663, and Sadabahar, were evaluated in the present study. All the genotypes were grown on 4 kg of processed soil in each pot at three levels of added P, namely control (0), 13.5 mg P kg^{-1} soil (sub-optimum), and 27 mg P kg^{-1} soil (optimum) in triplicates. Six healthy seeds were sown in each pot, and after germination four uniform plants were retained. Moisture content was maintained at optimum level (12%) throughout the experimental period with deionized water. Recommended doses of N, K, S, and Zn were applied on a soil-weight basis as basal in order to obtain 20 kg N, 30 kg K, 20 kg S, and 5 kg Zn ha^{-1}. Phosphorus was added as diammonium phosphate. The crop was harvested after 90 d.

Plant Analysis

After harvest, roots were thoroughly washed to remove soil particles and plants were divided into roots and shoots. All the plant parts were oven-dried at 70°C for 48 h and dry weights were recorded. Shoot samples were then ground and analyzed for P. Phosphorus was extracted with a tri-acid mixture of nitric acid, perchloric acid and sulfuric acid (3:1:1) and diluted with water to a constant volume. The concentration of P in the extract was determined by using the vanadomolybdate yellow color method (Jackson, 1973). Phosphorus uptake (milligrams per pot) by chickpea genotypes was computed from P concentration and dry-matter yield. Concentration of Zn, Fe, Cu, and Mn were determined by atomic absorption spectrophotometry. Phosphorus influx to xylem (PIX) was

calculated as follows (Zhu et al., 2002):

$$\text{PIX} = \frac{\text{Total P in shoot}}{\frac{1}{2}(\text{root biomass}) \times \text{day}} (\text{mg P/g DW/day})$$

assuming that there was a linear increase in root biomass production during the experimental period.

Efficiency Parameters

Phosphorus efficiency of chickpea genotypes was assessed using three criteria: shoot biomass in control (no P supply); P-uptake efficiency (PUPE), calculated as the amount of P in the plant divided by the amount of P supplied in the soil; and P-utilizing efficiency (PUSE), calculated as the shoot dry weight divided by the P content in shoot (Osborne and Rengel, 2002b). The data were analyzed by ANOVA. Correlation analysis was performed between P concentration and yield and root growth and P-uptake parameters. The LSD at $P = 0.05$ was used to separate the means of each treatment.

RESULTS

Shoot and Root Growth

The genotypes responded differently to levels of P in terms of root and shoot growth (Table 2). Root dry weight ranged from 0.56 to 1.96 g pot^{-1} in the control, with a mean of 1.01 ± 0.30 g pot^{-1}. With 27 mg P kg^{-1}soil (optimum) there was a significant increase in root dry weight ranging from 0.95 to 3.07 g pot^{-1}, with a mean of 1.76 ± 0.83. Plant height in the control ranged from 14.0 to 20.6 cm, with a mean of 17.1 ± 2.4 cm. There was no significant increase in plant height with sub-optimum level of P application. However at optimum P, plant height of chickpea genotypes ranged from 16.6 to 29.6 cm, with a mean of 22.9 ± 3.2 cm, which was significantly superior to the control. Though there was improvement in the number of branches per plant with increased P supply, increases were non-significant (data not shown).

Shoot growth under the control treatment ranged from 1.06 to 3.13 g pot^{-1}, with a mean of 1.57 ± 0.52 and coefficient variation of 33%. Genotypes BG-256, HK 94-134, Phule G-5, and Vikash produced higher shoot biomass in absence of P supply, while GNG-663, Sadabahar, Padhey, Pusa 209, KPG 59, and BG 413 produced lower biomass. With the addition of 13.5 mg P kg soil^{-1}, mean shoot dry matter increased from 1.57 (control) to 2.04 g pot^{-1} ($\pm$0.69: 34%), which was non-significant, but 27 mg P kg^{-1} resulted in significant shoot dry-matter increase (3.69 g pot^{-1}). At the optimum P supply, KPG-54 produced the highest shoot biomass (8.34 g pot^{-1}) followed by BG-256 (5.84 g pot^{-1})

Table 2
Variations in the response of 20 chickpea genotypes at different levels of added P

Genotype	Root dry wt. (g/pot)			Shoot dry wt. (g/pot)			Root/Shoot ratio		
	0	13.5 mg kg^{-1}	27 mg kg^{-1}	0	13.5 mg kg^{-1}	27 mg kg^{-1}	0	13.5 mg kg^{-1}	27 mg kg^{-1}
Phule G-5	1.17 ± 0.07	1.28 ± 0.07	2.12 ± 0.30	2.22 ± 0.02	2.36 ± 0.28	4.56 ± 0.37	0.53	0.54	0.46
KPG-59	0.85 ± 0.05	1.04 ± 0.10	4.41 ± 0.20	1.21 ± 0.19	1.44 ± 0.11	8.34 ± 1.40	0.70	0.72	0.53
PUSA-209	1.23 ± 0.08	1.30 ± 0.10	2.35 ± 0.05	1.19 ± 0.05	1.32 ± 0.07	4.97 ± 0.50	1.03	0.98	0.47
BG-413	0.69 ± 0.04	0.78 ± 0.04	1.79 ± 0.29	1.21 ± 0.02	1.38 ± 0.22	4.18 ± 0.35	0.57	0.57	0.43
BG-256	1.35 ± 0.15	1.40 ± 0.09	2.40 ± 0.30	3.13 ± 0.40	3.42 ± 0.13	5.84 ± 0.01	0.43	0.41	0.41
K-850	1.04 ± 0.01	1.25 ± 0.30	1.80 ± 0.30	1.57 ± 0.03	1.65 ± 0.29	4.96 ± 0.07	0.66	0.76	0.36
Pant G-114	0.79 ± 0.09	0.77 ± 0.02	1.35 ± 0.26	1.34 ± 0.16	1.49 ± 0.12	3.28 ± 0.45	0.59	0.52	0.41
SAK 1-9516	1.06 ± 0.09	1.10 ± 0.04	2.17 ± 0.30	1.68 ± 0.03	2.35 ± 0.26	5.55 ± 0.16	0.63	0.47	0.39
GPF-2	0.80 ± 0.09	0.91 ± 0.01	1.13 ± 0.12	1.46 ± 0.21	1.51 ± 0.04	2.42 ± 0.33	0.55	0.60	0.47
Vikash	0.95 ± 0.01	1.06 ± 1.12	1.15 ± 0.15	1.99 ± 0.19	2.1 ± 0.05	3.57 ± 0.07	0.48	0.50	0.32
Radhey	0.56 ± 0.08	0.85 ± 0.15	0.95 ± 0.01	1.13 ± 0.03	1.33 ± 0.20	1.80 ± 0.06	0.50	0.64	0.53
GCP-101	1.05 ± 0.10	1.22 ± 0.07	1.90 ± 0.11	1.33 ± 0.30	2.89 ± 0.10	3.35 ± 0.29	0.79	0.42	0.42
DCP-92-3	0.91 ± 0.01	0.97 ± 0.05	1.50 ± 0.11	1.39 ± 0.34	1.88 ± 0.04	2.72 ± 0.16	0.65	0.52	0.50
HK 94-134	1.96 ± 0.20	2.12 ± 0.02	3.07 ± 0.40	2.54 ± 0.02	3.77 ± 0.30	4.07 ± 0.24	0.77	0.56	0.75
RSG-888	1.05 ± 0.19	1.12 ± 0.08	1.10 ± 0.20	1.54 ± 0.10	1.80 ± 0.10	1.84 ± 0.03	0.68	0.62	0.60
GCP-105	1.06 ± 0.04	1.16 ± 0.10	1.29 ± 0.02	1.63 ± 0.30	2.12 ± 0.20	2.66 ± 0.30	0.65	0.55	0.48
JG-315	0.78 ± 0.06	0.84 ± 0.09	1.08 ± 0.20	1.40 ± 0.20	1.49 ± 0.05	2.35 ± 0.20	0.56	0.56	0.46
Vijay	1.12 ± 0.08	1.33 ± 0.20	1.34 ± 0.06	1.31 ± 0.26	2.50 ± 0.28	2.91 ± 0.01	0.85	0.53	0.46
GNG-663	0.81 ± 0.09	1.28 ± 0.13	1.34 ± 0.02	1.06 ± 0.11	2.02 ± 0.01	2.19 ± 0.15	0.76	0.63	0.61
Sadabahar	1.01 ± 0.08	1.45 ± 0.05	1.49 ± 0.01	1.12 ± 0.07	2.08 ± 0.20	2.26 ± 0.03	0.90	0.66	0.66
Mean	1.01	1.16	1.76	1.57	2.04	3.69	0.65	0.59	0.49
SD	0.30	0.31	0.83	0.52	0.69	1.65	0.15	0.12	0.10
LSD (5%)	0.74			1.52			0.18		

and SAK-1-9516 (5.55 g pot^{-1}). Higher root/shoot ratios were observed in all genotypes with increased levels of P application.

Phosphorus Concentration and Uptake

Phosphorus concentration in control pots varied from 0.84 to 1.54 g kg^{-1} shoot dry weight, with a mean of 1.12 (Table 3). Without P application, GNG-663, Sadabahar, RSG-888, K-850, and Phule G-5 maintained high P concentration. With 13.5 mg P kg^{-1}, the concentration increased to 2.0 g kg^{-1} shoot and further to 2.73 g kg^{-1} with 27 mg P kg^{-1}. Phosphorus uptake in the control ranged from 0.95 to 3.07 mg pot^{-1} (mean 1.75 ± 0.61), which increased significantly from 3.28 to 24.22 mg P pot^{-1} with 27 mg P kg^{-1} (mean 10.16 ± 5.10).

Table 3
Variations in shoot concentration and P uptake in chickpea genotypes at different levels of added P

	P Concentration (g kg^{-1} shoot DW)			P uptake (mg/pot) Mean		
Genotype	0	13.5 mg kg^{-1}	27 mg kg^{-1}	0	13.5 mg kg^{-1}	27 mg kg^{-1}
Phule G-5	1.26 ± 0.07	2.22 ± 0.31	2.29 ± 0.20	2.81	5.24	10.44
KPG-59	0.84 ± 0.01	2.16 ± 0.06	2.93 ± 0.40	1.02	3.11	24.44
PUSA-209	1.14 ± 0.05	1.74 ± 0.03	3.92 ± 0.41	1.36	2.30	19.48
BG-413	1.18 ± 0.12	2.09 ± 0.19	3.52 ± 0.24	1.43	2.83	14.71
BG-256	0.97 ± 0.01	1.74 ± 0.09	2.25 ± 0.09	3.04	5.95	13.14
K-850	1.27 ± 0.05	2.15 ± 0.01	2.56 ± 0.24	1.99	3.55	12.70
Pant G-114	0.71 ± 0.01	1.70 ± 0.02	2.57 ± 0.04	0.95	2.53	8.43
SAK 1-9516	1.11 ± 0.11	1.20 ± 0.10	2.38 ± 0.26	1.86	2.82	13.21
GPF-2	0.86 ± 0.02	1.31 ± 0.01	2.78 ± 0.48	1.26	1.98	6.73
Vikash	1.02 ± 0.12	1.54 ± 0.08	2.10 ± 0.02	2.03	3.23	7.50
Radhey	0.88 ± 0.09	1.34 ± 0.21	1.82 ± 0.05	0.99	1.78	3.28
GCP-101	1.20 ± 0.05	1.83 ± 0.11	2.39 ± 0.32	1.60	5.29	8.01
DCP-92-3	1.07 ± 0.02	1.76 ± 0.20	3.15 ± 0.31	1.49	3.31	8.57
HK 94-134	1.21 ± 0.03	1.81 ± 0.25	2.45 ± 0.34	3.07	6.82	9.97
RSG-888	1.30 ± 0.02	2.11 ± 0.25	2.21 ± 0.19	2.00	3.80	4.07
GCP-105	1.17 ± 0.02	2.48 ± 0.30	2.91 ± 0.24	1.91	5.26	7.74
JG-315	1.15 ± 0.07	1.95 ± 0.31	2.7 ± 0.24	1.61	2.91	6.35
Vijay	1.13 ± 0.05	2.61 ± 0.21	3.20 ± 0.13	1.48	6.53	9.31
GNG-663	1.54 ± 0.04	2.92 ± 0.32	3.10 ± 0.05	1.63	5.9	6.79
Sadabahar	1.31 ± 0.03	3.55 ± 0.05	3.70 ± 0.04	1.47	7.38	8.36
Mean	1.12	2.00	2.73	1.75	4.13	10.16
SD	0.19	0.56	0.54	0.61	1.74	5.10
LSD (5%)	0.66			4.3		

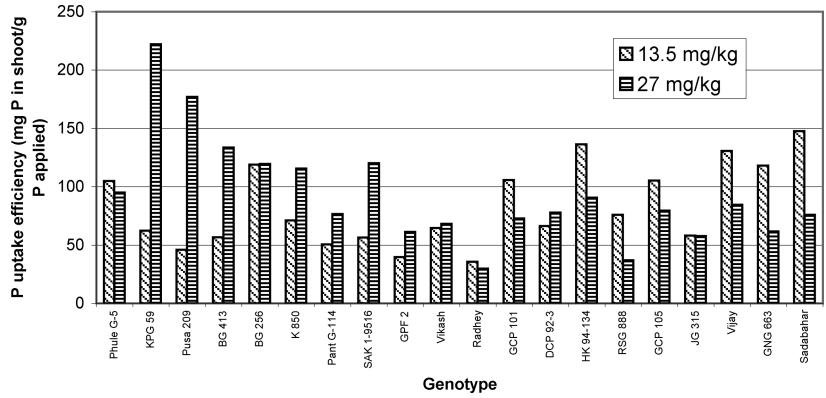

Figure 1. Phosphorus uptake efficiency in chickpea genotypes at different levels of added P.

Phosphorus Uptake Efficiency

Phosphorus uptake efficiency (PUPE) indicates the ability of a genotype to take up or acquire P from a unit of applied P. The phosphorus-uptake efficiency of 20 chickpea genotypes at two levels of added P is presented in Figure 1. At 13.5 mg P kg^{-1}, the PUPE ranged from 35.6 to 147.6 mg P g^{-1} P applied, and at 27 mg P kg^{-1}, it ranged from 29.8 to 222.2 mg P g^{-1}. Among genotypes, KPG 59 followed by Pusa 209, BG 413, BG 256, SAK 1-9516, and K 850 showed higher PUPE of above 100 mg P per gram of applied P at higher levels of P applied (27 mg P kg^{-1}). However, at sub-optimum level, genotypes Sadabahar, HK 94-134, Vijay, BG 256, GNG 663, GCP 101, GCP 105, and Phule G-5 showed higher PUPE above 100 mg P per gram of applied P.

Phosphorus-Utilization Efficiency

This index reflects how well cultivars utilize absorbed P to produce biomass. Phosphorus-utilization efficiency (PUSE) was higher in the control and gradually decreased with increasing P levels (Figure 2). Genotypes Pant G-114, KPG 59, GPF 2, Radhey, and BG 259 showed relatively higher PUSE. At higher levels of applied P, Radhey showed the highest PUSE. Among the three P-efficiency parameters, considerable variation among genotypes was observed.

Micronutrient Concentration and Uptake

Application of P at 13.5 mg kg^{-1} improved Zn concentration and further increase to 27.0 mg P kg^{-1} resulted in a significant decrease ($P < 0.05$) (Figure 3).

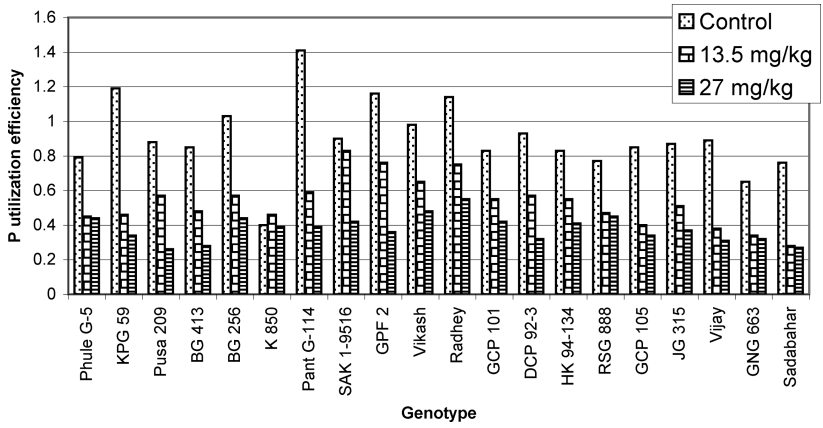

Figure 2. Phosphorus-utilization efficiency in chickpea genotypes at different levels of added P.

The mean Zn concentration increased from 22.1 ± 0.72 to 25.3 ± 0.53 μg g^{-1} at 13.5 mg P kg^{-1} and decreased to 20.8 ± 0.36 μg^{-1} at 27.0 mg P kg^{-1}. Among genotypes, HK-94-134 showed the highest Zn concentration at all levels of applied P. In the control, genotype Sadabahar at 13.5 kg P kg^{-1}, and genotypes BG-256 and DCP-92-3 at 27.0 mg P kg^{-1} maintained higher shoot Zn concentration. Among genotypes, KPG-59, BG-256, RSG-888, and JG-315 showed a Zn concentration below the critical limit of 20 μg Zn g^{-1} dry weight (DW) at 27.0 mg P kg^{-1}. However, across the genotypes, Zn uptake increased with increasing P levels, with mean Zn uptake increasing from 34.8 ± 12.5 μg pot^{-1} in the control to 76.4 ± 32.6 μg pot^{-1} at 27.0 mg P kg^{-1}. Concentration of Fe differed significantly among genotypes at all three levels of P

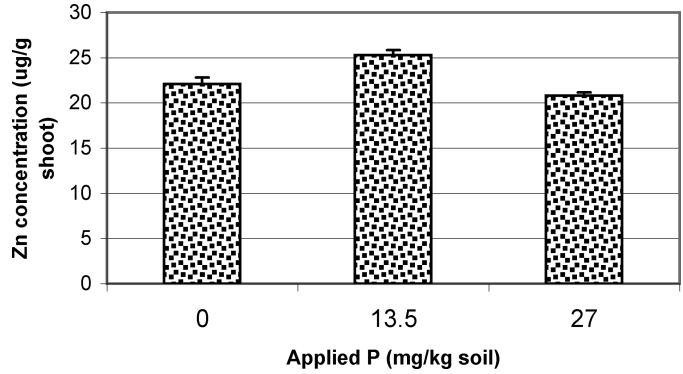

Figure 3. Effect of P application on shoot Zn concentration of 20 chickpea genotypes (lsd:1.22 at 0.05).

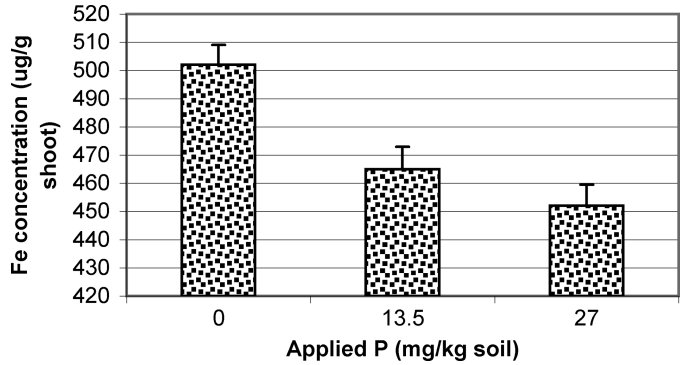

Figure 4. Effect of P application on shoot Fe concentration of 20 chickpea genotypes (lsd: 42.3 at 0.05).

application. In general, increasing levels of P application decreased Fe concentration (Figure 4). Iron concentration in shoot ranged from 360 ± 9.6 to 622 ± 10.8 μg g^{-1} in the control, from 351 ± 7.8 to 561 ± 15.0 μg g^{-1} at 13.5 mg P kg^{-1}, and from 350 ± 1.5 to 528 ± 7.6 μg g^{-1} at 27.0 mg P kg^{-1}. Among genotypes, Radhey and BG-413 showed higher Fe concentration at all levels of P application. The mean Fe concentration in shoot decreased from 502 ± 7.1 μg g^{-1} in the control to 452 ± 7.5 μg g^{-1} at 27.0 mg P kg^{-1}. The mean Fe uptake increased from 773 μg pot^{-1} in the control to 1655 μg pot^{-1} at 27.0 mg P kg^{-1}.

With increasing P levels, Cu concentration increased up to 13.5 mg P kg^{-1} and decreased significantly ($P < 0.05$) with further increase in P up to 27.0 mg kg^{-1} (Figure 5). Copper concentration ranged from 2.4 ± 0.3 to 7.7 ± 0.2 μg g^{-1} in the control, from 1.8 ± 0.3 to 7.5 ± 0.6 μg g^{-1} at 13.5 mg P kg^{-1}, and

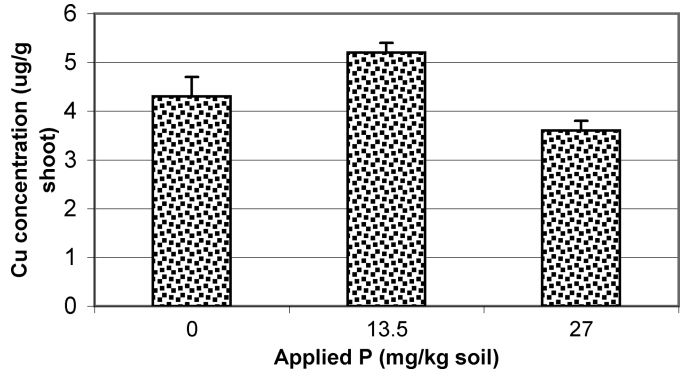

Figure 5. Effect of P application on shoot Cu concentration of 20 chickpea genotypes (lsd: 1.10 at 0.05).

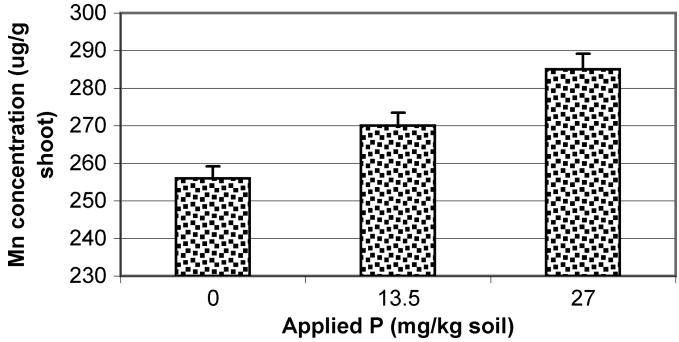

Figure 6. Effect of P application on shoot Mn concentration of 20 chickpea genotypes (lsd: 17.6 at 0.05).

from 1.6 ± 0.2 to 7.7 ± 0.5 μg g^{-1} at 27.0 mg P kg^{-1}. Among genotypes, GCP-101 maintained the highest Cu concentration, followed by JG-315, while BG-256 showed the lowest. At 27.0 mg P kg^{-1}, GCP-101 maintained the highest concentration, above 7 μg g^{-1}, whereas BG-413, BG-256, and K-850 recorded concentrations below 2 μg g^{-1}. Wide variations of 80%, 53%, and 54% were observed for Cu uptake among 20 genotypes under the control, 13.5, and 27.0 mg P kg^{-1} treatments, respectively.

Increasing P levels gradually increased the Mn concentration (Figure 6). However, mean increase was statistically significant only at 27 mg P kg^{-1}. The mean Mn concentration increased from $256 \pm 3.2\mu$g g^{-1} (control) to 285 ± 4.2 μg g^{-1} at 27 mg P kg^{-1}. The genotype RSG-888 showed the highest Mn concentration and KPG-59 showed the lowest at all P levels.

DISCUSSION

Since chickpea in India is grown mainly on P-deficient soils, genotypes that have better P uptake and efficiency in P-stressed soils can be preferred over others. This study clearly recorded significant differences in growth, P uptake, and PUSE among 20 chickpea genotypes, under both P stress and P optimum conditions, indicating the existence of genetic differences for these traits. The study also revealed the interactive effects of P and micronutrient nutrition. Significant increase in root and shoot biomass with P was noted in most genotypes only with optimum P level (27 mg P kg^{-1} soil), as a major part of the added P at sub-optimum level (13.5 mg P kg^{-1} soil) could have been fixed due to relatively high exchangeable calcium (Ca) in the soil, as shown by the very low available P recorded in soil (1.43 mg P kg^{-1}).

A genotype can be considered more efficient than other if it absorbs relatively more P from soil and makes better use of the absorbed P to produce biomass. From the three criteria followed in the study, some genotypes were

found to be more P efficient according to one criterion while some other genotypes were more efficient according to other criteria. This result could be due to the variable weight given while computing different PUSE parameters (Osborne and Rengel, 2002c).

As per the first criterion (growth at low P supply), genotypes BG 256, HK 94-134, and Phule G-5 were found to be more efficient (Table 2). Incidentally, BG 256 is one of the popular genotypes widely grown in different parts of India. Though the soil was severely P deficient, BG 256 maintained higher biomass in the control treatment. Even under sub-optimum P levels (13.5 mg P kg^{-1}soil), HK 94-134 and BG 256 maintained higher shoot biomass. At optimum P levels (27 mg kg^{-1}soil), genotype KPG 59 performed better than BG-256; however, BG-256 produced higher shoot biomass than the rest of the 18 genotypes. Generally, the best-performing genotypes differend under low and optimum P supply, but BG 256 was exceptional in maintaining higher shoot biomass under both P deficiency and P sufficiency. Interestingly, genotypes that maintained higher P concentration did not show a proportionate increase in biomass. Thus, correlations between P concentration and shoot dry weight were non-significant. Therefore, P concentration as such is of little importance in screening the genotypes for better performance under P-deficient conditions, as observed by other authors (Osborne and Rengel, 2002c).

Based on the second criteria of PUPE, the genotypes KPG-59 followed by Pusa-209 were most efficient under optimum P supply, but these genotypes showed low PUSE with sub-optimum P supply. Under suboptimum P, genotypes Sadabahar and HK 94-134 were found to be superior, but when the P level was increased to optimum, these genotypes failed to maintain their high use efficiency. However, BG 256 was equally efficient at both levels of applied P. The PUPE, taken in conjunction with the size of the root system, can provide an indication of the extent to which P acquisition is due to root volume and its functioning (Osborne and Rengel, 2002a). In this study, root dry weight of 20 chickpea genotypes showed a highly significant correlation with P uptake (Figure 7) at all three levels of P namely the control ($r = 0.77^{**}$), 13.5 mg P kg^{-1} ($r = 0.77^{**}$), and 27 mg P kg^{-1} ($r = 0.84^{**}$). Marschner (1998) stated that genotypic differences in nutrient acquisition arise primarily through differences in root morphology, root surface area of absorption, and rhizosphare chemistry. As P is relatively less mobile in soil, root size is particularly important in exploration of a large soil volume or in altering its release.

PUSE (the third criterion) in Pant G-114 and KPG-59, GPF-2, Radhey, and BG-256 was higher than in the control and decreased considerably with P addition. Other genotypes also recorded lower PUSE at higher P levels. Gourley et al. (1993) opined that screening germplasm for shoot dry mass or harvestable product under low-P conditions may provide the best estimate of productivity in low-P soils. While evaluating several cereal genotypes for P uptake and utilization, Osborne and Rengel (2002a) stated that higher P uptake under P-deficient conditions, even when combined with lower utilization efficiency, is

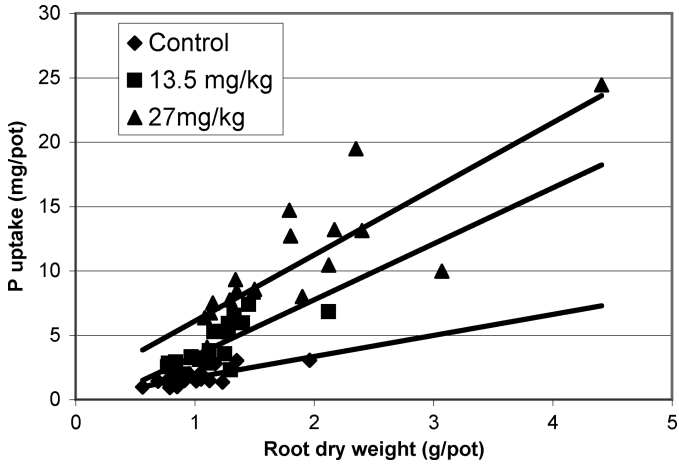

Figure 7. Relationship between root dry weight and P uptake in chickpea genotypes at different levels of added P.

still a desirable trait that would ensure good growth under P-limiting conditions. In a recent study with 42 wheat genotypes, Manske et al. (2000) related the genotypic variation in P-use efficiency to grain yield and concluded that high root density in the topsoil was the most important trait for better P absorption.

In India, besides P deficiency, several micronutrient deficiencies coexist in most chickpea-growing areas. However, application of P up to 80 kg P_2O_5 ha^{-1} is recommended for chickpea (Srinivasarao et al., 2003). The antagonistic effect of P and Zn has been well established (Zhu et al., 2002; Gianquinto et al., 2000; Singh et al., 1988). Results of this study indicate that at lower levels (13.5 mg kg^{-1}) of P application, Zn concentration increased in 18 out of 20 genotypes tested. As the experimental soil was deficient in both available P (1.43 mg kg^{-1}) and Zn (0.4 mg kg^{-1}), a positive interaction was observed between these elements at lower P application. However, at higher P levels, there was an antagonistic interaction between P and Zn concentration. This result was confirmed by the positive correlation between P and Zn concentration in the no-P control. Subbarao and Rupa (2003) stated that antagonism between P and Zn is observed when both elements in soil are deficient, but only one of them is applied. Through balanced application of P and Zn, the antagonism can be neutralized and converted into a synergistic effect. The relationship between P uptake and Zn concentration was significantly negative ($P < 0.05$) in the present study. An inverse relationship between shoot P accumulation and Zn concentration was related to P translocation from roots to shoots (Zhu et al., 2002). However, in our studies, the relationship between P influx and Zn concentration was negative but non-significant (Figure 8). Therefore, reduction in Zn concentration can be explained by a dilution effect caused by increased biomass, as reported by Lambert et al. (1979). Present results suggest that under

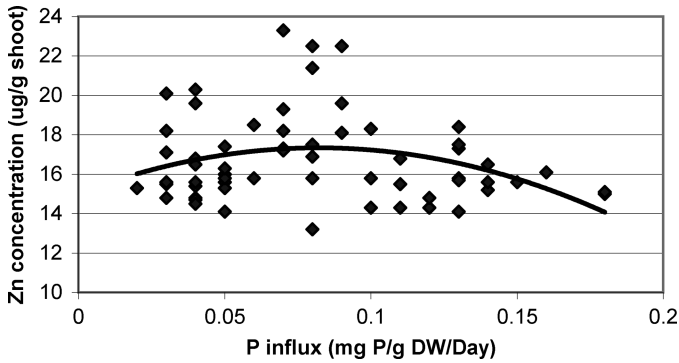

Figure 8. Relationship between P influx and Zn concentration in chickpea (n = 60).

conditions of deficiency of both P and Zn in soil, application of P alone at higher doses negatively affects the Zn nutrition. Therefore, application of Zn along with P fertilization is critical for optimum nutrition of chickpea. As with P, marked differences among genotypes were also found for Zn nutrition. Genotypes HK-94-134 and GCP-101 were found to be Zn efficient, whereas KPG-59, BG-256, RSG-888, and JG-315 showed Zn concentrations below the critical limit at 27.0 mg P kg^{-1}.

Iron concentration was significantly reduced at 13.5 mg P kg^{-1} except in two genotypes, Pant G-114 and GPF-2, which were not affected by P fertilization. The relationships of P concentration and uptake with concentration of Fe, being negative ($P < 0.05$), suggest that Fe nutrition could be the yield-limiting factor under adequate P fertilization. A positive relationship was observed between P and Cu concentration at lower level of P, whereas it was negative at higher levels of P. At 27.0 mg P kg^{-1}, genotypes DCP-92-3 and GCP-101 maintained higher Cu concentration. Buerkert et al. (1998) reported that increase in P application reduced Cu concentration in millets, but the mechanism of P-Cu interaction in soil-plant systems was not reported. Higher P availability reduced Cu concentration in barley genotypes due mainly to dilution effect (Zhu et al., 2002). A similar effect was reported in maize by Lambert et al. (1979). Unlike concentration of other micronutrients, Mn concentration increased with increasing P levels. The relationship between P and Mn concentration was significantly positive ($P < 0.05$). However, the mean increase in Mn concentration was statistically significant only at 27.0 mg P kg^{-1}. Among genotypes, RSG-888 was found to be highly Mn efficient, and KPG-59 was Mn inefficient at all P levels.

CONCLUSIONS

The present set of experiments clearly demonstrated the genotypic differences in P and micronutrient nutrition among chickpeas in India. The genotype BG 256 was found to be among the top five genotypes per all three efficiency

criteria followed in the present study. AK 94-134 and Phule G-5 were other genotypes that performed well under P-deficient conditions or low-input agriculture. Under high-input conditions, KPG 59 and PUSA 209 were found to be superior. BG-256 is a popular chickpea genotype with high yield potential under P-stress conditions, and, with its higher P uptake and utilization potential, is quite popular in India. Thus this genotype can be a good source of genetic material for improving PUSE of chickpea. This discovery could be an important step forward in chickpea-breeding programs for low-input management systems. The present study also demonstrated the interaction effects of P and four important micronutrients in the 20 chickpea genotypes. These interactions bear important implications for nutrient-management practices for chickpea in India. Most chickpea-growing regions of the country are deficient in P as well as micronutrients, and farmers apply only P. The results also demonstrated wide variations among genotypes in Zn, Fe, Cu, and Mn efficiency. A judicious approach for genetic improvement and correction of micronutrient deficiencies can achieve the object of higher chickpea production under the low-external-input farming systems that are common among small landholders in India.

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