GENETIC VARIATION FOR PHOSPHORUS UPTAKE IN SELECTED GENOTYPES OF BLACKGRAM (*Vigna mungo* L. Hepper)

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1. INTRODUCTION

Phosphorous (P) is one of the most important elements that significantly affects plant growth and metabolism and low P availability is a primary constraint to plant productivity, particularly in weathered soils in tropics and sub tropics when P is commonly bound to iron and aluminium oxides through chemical precipitation or physical adsorption. The P requirement is in the range of 0.3 to 0.5 per cent of plant dry weight during the vegetative stage of the plant growth. Plants obtain their P in soluble ionic forms (HPO_4^- and $H_2PO_4^-$). The total content of phosphorous in soil is normally low in order of 0.01 to 0.20 per cent P is one of the least available mineral nutrients to the plant in many cropping environments based on its contribution to the biomass as macronutrient (Goldstein et al., 1988). Sub-optimal levels of P can lead to yield losses to the tune of 5-15 per cent of the maximal yields and attempts to ameliorate this situation by application of additional P fertilizer is becoming increasingly economically and ecologically unsound practice, as the price of water soluble phosphatic fertilizer is very high because of using mineral acids and non-renewal source of energy for their manufacturing. Hence, low P availability is especially problematic for leguminous crops, since legume nodules responsible for N fixation have a high P requirement (Vance, 2001).

In response to persistently low levels of available P in the rhizosphere, plants have developed highly specialized adaptive mechanism through morphological, architectural and biochemical changes that enable more efficient acquisition and utilization of the limited P. Plants which have the ability to increase Pi uptake, either by extensive root growth or increased rate of Pi uptake or a greater ability to absorb Pi due to increased root elongation show superior growth in low P soils. Therefore, P uptake not only depends on the amount of available P in soil but also on plant properties.

Plant species differ extensively in the magnitude of P uptake, translocation, accumulation and use of mineral elements. Diversity among genotypes, cultivars, varieties lines, inbreeds etc., within a plant species for element uptake, translocation, distribution and use have been recognized for many years. Many differences are under genetic control, but their expression may be altered dramatically when plants are grown under different environments.

From mineral nutrition point of view, a genotype is more efficient than others, when it absorbs and mobilizes more P from soils (P acquisition efficiency) and or makes better use of the absorbed P to produce biomass (P use efficiency). Improvement of P efficiency of crop plants by selection seems possible (Caradus, 1994).

The possibility of exploiting genotypic differences for improving nutrient efficiency of crop plants has received increased attention in recent years. P efficient genotypes can be useful for maintaining high productivity in low input agriculture. These genotypes have been shown to be useful in breeding plants that are better in acquiring nutrients from the soil and or to make more efficient use of nutrients in their metabolic process.

Godwin and Wilson (1976) stated that a useful starting point in determination of P efficiency is a knowledge of the genetic variability of P metabolism which can be utilized in breeding programme. Additional breeding for new crop genotypes with improved P efficiency may be a supplementary alternative for reducing the traditional amendments of soils for the application of fertilizer (Batten, 1992 and Kajjidoni *et al.,* 2002). For successful exploitation of such alternative approaches, the knowledge on the extent of genetic variation among existing genotypes appears to be mandatory.

Pulses have been cultivated as protein sources, under low input agriculture for thousands of years. Pulses constitute the main sources of essential protein and a for predominantly vegetarian population of India.

Among these blackgram or urd (*Vigna mungo* L. Hepper) is pulse crop of many Asian countries and it belongs to tribe phaseolus family leguminoseae with chromosome number 2n=22. . Urd is said to have originated in India when it is most widely grown and highly esteemed grain legume (Chatterjee and Bhattacharya, 1986).Urd bean occupies about 14 per

cent of the total area under pulse in the country and ranks fourth in area and production after chickpea, pigeonpea and mungbean.

In India alone it occupies about 3.17 million hectare and annual production of urd bean in India is about 1.33 million tones. Urd is highly prized pulse and cultivated under a wide range of predominantly rainfed farming system in dry and intermediate agro ecological zones on marginal lands with low moisture and fertility conditions.

Besides it is a important protein source for people in the cereal-based society because it is rich in phosphoric acid among pulses, rich in source of vegetable protein (20-25%) with some essential minerals and vitamins for the human body.

Blackgram suffers from want of nutrients, especially immobile element like P. Phosphorus is an essential plant nutrient plays a vital role in the root development, cell division and seed formation. More importantly it is a component of ATP and ADP, which are involved in the energy transformation driving most of the biochemical reactions including respiration and photosynthesis. Hence low phosphorous availability cultivated extent and production of blackgram vary from year to year with a decreasing trend and consequently, the production is not sufficient for the demand.

Although in blackgram there are substantial differences in the ability to utilize the P as a P sources. For assessing the scope of genetic improvement of this phenomenon and also for quantifying the P solubilizing activity (of root exudates) and altered root architecture (increased root surface area) are important to analyze in relation to differential P availability.

Little is known about the factors determining differences in the ability of blackgram genotypes for phosphorous efficiency (uptake and utilization). Therefore, the identification of genotypes and to know the mechanism of efficiency that causes the differences in P uptake and utilization is required. The presence of genetic variation in P uptake is essential to devise breeding strategies for the development of appropriate genotypes, which could utilize fixed forms of P more efficiently. Therefore, the objectives of current investigation are as follows.

1. To assess the genotypic variation in P uptake under low and optimum P availability.
2. To study the variation in plant and root morphological traits under low and optimum P availability.
3. To study the nature of correlation between plant and root morphological traits under different levels of P variability.

2. REVIEW OF LITERATURE

There is a great disparity in distribution of phosphorus between plant cell and soil solution. Low levels of phosphorous availabale in the rhizosphere, makes it one of the major growth – limiting factors in many leguminous crops. The efficacy of phosphorous applied through soil is very low owing to its fixation in soils. Thus there is a need to evolve varieties having wider adaptability to low nutrient (deficient P) condition.

A thorough understanding of the genetic variation for different traits and character association among genotypes are important for any crop improvement programme to be successful. However, extensive field studies to explore genotypic variation for phosphorus uptake are rare, which makes it difficult to assess, how genotypes can be manipulated through breeding efforts. The available literature in this regard has been reviewed under the following headings.

2.1 Genetic variability

2.2 Correlation studies

2.3 Path coefficient analysis

2.1 Genetic variability

The 21st century has achieved genome mapping of complex traits of the organism but it could not understand completely the nature of roots as the post embryonic development of the plants are dependent on both intrinsic genetic factors and environmental factors. Varietal differences in nutrient efficacy are based on genetic variation in certain physiological or morphological attributes. In this regard, root parameters such as length, distribution, surface area and activity (exudation of organic acid) are important for nutrient uptake especially under conditions of low nutrients. P present in soil solution in only micro molar concentration because it is commonly bound to many soil constituents that make it unavailable. In this regard, it is very important to know how the roots behave under low nutrient conditions and what are the mechanisms that the roots put forth for the best survivability of the plants and amount of variability that exist under low P conditions is very important for genetic improvement and keeping these in consideration an effort was made to review regarding these aspects.

The review on genetic variability is presented under following subheadings.

2.1.1 P deficiency, plant growth and development

2.1.2 Genotypic variation for root and shoot morphological traits and phosphorus uptake

2.1.3 Genotypic variation for morphological, seed yield and its component traits

2.1.4 Adaptation of plant to low P availability

2.1.1 P deficiency, plant growth and development

Phosphorus is an essential plant nutrient plays a vital role in the root development, cell division and seed formation. More importantly it is a component of ATP and ADP, which are involved in the energy transformations, driving most of the biochemical reactions including respiration and photosynthesis.

Atkinson (1973) described a number of general effects of P deficiency on plant growth in a wide range of species from different ecological habitats. Most species followed similar pattern regardless of ecological origin. Deficiency affected root/shoot ratio, hydration and leuco-anthocyanin content. Deficiency caused an increase in root/shoot ratio of all species. Leuco-anthocyanin content showed quantitative increase with increasing severity of deficiency. The deficiency produces three common features.

a) Leaves are the first organs to be affected and their growth reduced most severely.

b) Root growth is the least affected, root/shoot ratio increased with time but increase is proportionate and greater in deficient plants.

c) Leaf development is delayed by deficiency effect of different concentration of P.

The root/shoot ratio increases with decreasing the P supply, a situation mainly due to the greater reduction in the growth rate of the shoot. The P concentration in both the shoot and root decreases with decreasing P supply although the weight decrease is more marked in the root. As the experimental P supply is reduced, the root keeps growing at similar rate progressively with less P and total dry weight of the plants was reduced by 40%.

Liao *et al.* (2001) conducted an experiments on several crops including bean and studied the effect of P starvation on leaf area consistency and crops grown under varying phosphorus sand culture and soil culture sources. Under low phosphorus condition, plant growth was severely stunted and leaves become small and thick, some anthocyanin pigments were observed on leaves. Several other authors also reported a rapid and severe effect of P deficiency on leaf growth. Brown and Lynch (2001) reported reduction in leaf area was the major component for decrease in the total yield of leaf biomass under P deficiency.

Buso and Bluss (1988) studied fifteen lettuce cultivar representing three different morphological types which were grown in a sand alumina system under conditions of low (deficient) and high (sufficient) P supply. An efficient plant was defined as one that produced a large shoot fresh weight under low P concentrations. Cultivars within their respective groups varied significantly for some traits that appeared to be important in determining adaptation to P. This led to the conclusion that alumination of P in shoot tissue or the total P was main difference between efficient and inefficient cultivars. The butter head cultivars were the least efficient plants when grown under low P compared to the other groups, plants had lower translocation efficiently and a greater root:shoot ratio. The results of this study demonstrate that there was genotypic variability and/or genotype $\times$ environment interaction effects for shoot weight (yield) among the lettuce cultivars grown under low P conditions imposed in the sand alumina system.

2.1.2 Genotypic variation for root and shoot morphological traits and phosphorus uptake

Analysis of corn leaf tissue (Baker *et al.,* 1967) revealed significant difference among corn inbreds and hybrids for concentrations of various chemical elements, including phosphorous. They found the existence of genetically controlled phosphorous accumulation variation and indicated that at least two genetic factors involved with the possibility of dominance for the lower phosphorous level. This study failed to indicate any relationship of leaf phosphorous concentration to grain yield.

Clark and Brown (1974) conducted an experiment on two corn inbreds namely PA 36 (high P accumulator) and WH (low P accumulator). P stress was created by varying amount of P added to the nutrient medium. When, P concentration was increased the amount of P in plant also increased from 0.2 to 0.9 per cent. Increased root growth at increased P and lowered pH of the nutrient solution was observed at all P levels in WH inbred than in PA 36. They also reported that increased P uptake or better adaptation of plants to P stress was a result of increased phosphate activity of the plant roots.

The above study indicated that roots find their own way of adjustment to stressed environment using phosphatase activity but there are other mechanisms through which roots adapt to low P conditions like root activity and architectural properties. In a study by Lindgren *et al.* (1977) using excised roots for identifying differences in rates of P absorption by 59 lines of *Phaseolus vulgaris*, large variations in P absorption rates between lines were noticed. They concluded that high variance for P absorption by excised roots was due to high environmental effect.

Larger root system provides greater root soil contact which was particularly important for uptake of P and other less mobile ions. They concluded that P uptake was often closely related to root length (Atkinson, 1991).

Reddy *et al.* (1993) studied difference in P absorption rates and efficiency of P utilization in seven genotypes of groundnut at low level of P. The efficient cultivars did not show any deficiency symptoms at low and had higher absorption rates and more P in the tops than roots and produced higher dry matter difference and the response was attributed to differential P absorption, translocation and utilization of P.

Alvaro *et al.* (1993) conducted an experiment for genotype screening and selection for tolerance to low P stress conditions. Using maize inbred lines, low and high P concentration levels were established that provided a reproducible and diffusion controlled availability of P to the plants at concentrations of 8 to 10 µm and 40 to 50 µm, respectively of culture medium solution P at the time of transplanting. The sand alumina culture medium was used to screen 20 maize inbreds. Increasing pot solution P concentration did increase plant dry matter production differentially among the maize inbreds evaluated. The analysis of variance for shoot dry matter accumulation and plant dry matter accumulation showed a highly significant interaction between inbreds and P accumulation. The inbreds B37, Oh40B, NY821, Pa36 and MS1334 were selected as tolerant (efficient) to low P in sand alumina medium.

Many authors observed higher root to shoot ratio on P deficiency plant associated with high production of carbohydrates being partitioned to roots and higher sugar concentration in roots (Cakmak *et al.,* 1994). They observed effect of starvation on leaf area per plant is consistent with the results of other authors who have concluded a rapid and severe effect of P deficiency on leaf growth. The PUE was not strongly affected during first half of the experiment suggesting that synthesis per unit leaf area was not affected.

Snapp *et al.* (1995) reported that low P treatment reduced biomass accumulation in shoot, pod and root tissues compared to high P treatment. In comparison to high P plants, low P plants had significantly reduced root length in the main root system. In contrast, low P plants maintained fine root length comparable to high P plants. Root biomass investment in high P plants was reduced to -54% and P investment by 43% for low P plants compared to high P. Phosphorus uptake from the P patch was 3 fold higher in high P plants compared to low P plants.

Gorny (1996) variation in shoot and root morphological traits and utilization of N and P was investigated in old and new oat cultivars. Plants were sown in sand vermiculite culture under high and low nutrient supply. They concluded that reduced nutrition stimulated root growth and the effect was genotype dependent. The response to limited supply of nutrients at the vegetative growth stage differed from the response at the maturity.

Ae *et al.* (1996) conducted an experiment to know the role of cell wall of roots in solubilizing sparingly soluble P in soil. They used groundnut, maize, soybean and sorghum for the study in pot culture experiment and supplied with P free Arnon's micronutrient solution and pots were filled with well weathered acid soils. Results indicated that groundnut had high ability to take up P from low P fertility soils when compared with other crops, suggesting as groundnut P uptake in low levels was not related to root development and root exudates. But, related with acidic pH of the groundnut root cells due to secretion of H^+ ions, which solubilizes more P than other crops. They suggested that an enlargement of root surface area through root length, root fineness and root hairs was beneficial to increase P solubilization.

Krishna (1997) observed significant differences among 25 genotypes of groundnut for total P efficiency of the genotypes including root length, rate of P uptake per root length. P efficiency was interpreted as higher uptake of certain genotypes which depended more on increased root length and increased exploration of soil, while others depended on greater P absorption rate and total P uptake per unit length. He concluded that selection for higher P absorption from soil was correlated with better root traits.

Ashok *et al.* (2002) conducted at pot culture experiment to study the genotypic variation for acquisition and use efficancy of native P in vertisol using five genotypes (Dsb-1, KHsb-2, J-335, PK-1162 and MACS-450). They observed depletion of both available and total P with plant growth in the absence of MPS organisms. KHsb-2 genotype had higher P content, root biomass, root-shoot ratio, higher dry matter accumulation and seed yield. Further, it had lower raise in the rhizosphere pH as compared to other genotypes, there by indicating its higher efficiency in P acquisition and utilization over others.

Chassot and Richer (2002) conduced experiments to study combined effects of depth, gradients of soil temperature, soil strength and level of soil P on the early growth of maize under controlled conditions and thus simulate the soil physical conditions in the field under conventional tillage, morphology and functioning of roots with regard to shoot growth and fertilizer utilization efficiency. Root to shoot ratio was higher on P deprived plants, which indicates that shootgrowth was more severely reduced than root growth. Brevedan *et al.* (2002) observed low P treatment reduced shoot growth significantly and main effect was a reduction on expansion of leaves (70%) and root growth was less affected by low P.

Lopez-brucio *et al.* (2002) studied the effect of P availability on development of root system in *Arabidopsis.* They found that under P limiting conditions (< 50 □m), the *Arabidopsis* root system undergoes major architectural changes in terms of lateral root number, lateral root density and primary root length. A primary adaptation to low P availability involves post embryonic developmental changes in root system, which are directed toward enhancing patterns of total root length, root hair elongation and lateral root formation.

Sun *et al.* (2002) studied morphology of root systems of different wheat (*Triticum aestivum* L.) genotypes under low P stress and studied the effect of external factors. The length of the root axis and root system and number of lateral roots were sharply increased under P stress. The number and length of root axis were significantly different under different levels of P supply. This implied that two traits were controlled by genotypes and external factors and they showed traits of lateral roots mainly depended on external factors.

Yong *et al.* (2002) studied the effect of localized supply of P on root morphology and architecture of two rice varieties *viz*., Azucena and IR1552. They found Azucena as more responsive to localized P supply due to more plasticity in root morphological and architectural adaptation. The increased root length was observed with high P supply, whereas the adaptation for low P was due to cluster-roots like fine roots. Results also indicated that the P deficiency signal comes from the low-P side, while enhanced root growth is realized on the high P side. They concluded that the induced changes in root morphology and architecture by localized supply would have physiological significance that P uptake by plants can be achieved by allocating a portion of the roots to the high P zone.

2.1.3 Genotypic variation for the root and shoot morphological traits and grain yield

Siophongco *et al.* (1997) conducted greenhouse experiments to develop screening methods and quantified variation in root traits among 144 double haploid lines (DHLs) in rice. Plants were harvested at 30 days after wet seeding and their root system was assessed. Average root diameters at 1 cm depth ranged from 0.78 to 1.15 mm with IR62266-42-6-2 and CT9993-5-1-1 M having root diameters of 0.90 and 0.99 mm respectively. Root dry weights ranged from 0.1511 to 0.9991 g with IR62266-42-6-2 (0.7120 g) having twice to that of CT9993-5-10-1-M (0.3275 g). The DHLs showed a wider range of values for each root traits, lines with desirable root traits were identified and data was used for QTL analysis. They concluded that root traits responded for P stress condition.

A greenhouse experiment was conducted to evaluate phosphorous (P) use efficiency of 10 promising genotypes of common bean (*Phaseolus vugaris* L.) with short and normal growth duration. The genotypes were grown on the oxisol at 25 mg P/kg (low P) and 150 mg P/kg (high P) of soil. Shoot and root dry weight, root length, P concentration in the shoot and P uptake in the shoot was significantly ($P<0.01$) affected by soil P concentration and genotype. However, P level did not effect root length and genotype had no effect on root dry

weight. There were no differences between short and normal growth duration genotypes in P-use efficiency (Fageria and Costa, 2000).

Gaume *et al.* (2001) investigated dry matter production, root/shoot ratio, root length and root exudation of organic acids and acid phosphatase in four maize genotypes grown under P deficient and P sufficient conditions in sterile hydroponic culture. They found increased root development and increased exudation of acid phosphatase under P deficient conditions in all low P tolerant cultivars, except for the Swiss cultivar. Effects on root formation and acid phosphatase were greater for low P tolerant than for the low P susceptible genotypes. Low P susceptible genotypes were characterized by high organic acid content in roots and low organic acid exudation. These mechanisms allow maize genotypes to adapt to soils, which are low in available P.

Kajjidoni *et al.* (2002) conducted a field experiment in vertisol to find out genotypic response of 29 advanced breeding lines of blackgram for P uptake involving two donor parents and two recommended varieties for phosphorous uptake at 45 DAS under three different P sources i.e., rock phosphate (RP), RP + phosphorous solubilzing bacteria (PSB) and single super phosphate (SSP). They reported that genotypes varied widely for phosphorous uptake under different sources of P nutrition. Mean P uptake in RP source was lowest, further suggesting greater scope of selection of genotypes as these exhibited wider uptake values under application of RP compared to other P sources and further suggested that differential uptake ability of genotypes can be exploited to identify suitable cultivars to utilize the fixed phosphorous in soil.

He *et al.* (2003) elucidated the effect of localized supply of phosphorus on root morphology and architecture and their effect on phosphorus uptake by rice plants. Two rice cultivars representing upland and lowland ecotypes grown in specially designed split and stratified soil cultures with low phosphorus red soil. They implied that a phosphorus deficiency signal from low phosphorus side may stimulate the growth of roots located in high phosphorus zone. The induced changes in root morphology and architecture may have both physiological significance and practical implication in that plant which can meet the demand for phosphorus with parts of the roots reaching the high phosphorus zone.

Ashok (2005) conducted a pot culture experiment in calcareous soil using 33 blackgram genotypes. He observed differences in shoot dry matter, seed yield and P uptake among the blackgram genotypes. Analysis of variance under P deficit condition indicated presence of significant differences among genotypes for all twenty characters except root dry weight, root P uptake at 45 DAS and pod length, 100-seed weight, root dry weight, harvest index and root P uptake at harvest and concluded that there was a significant differences among genotypes for growth, dry weight, yield and yield components under P deficient condition.

Hammond *et al.* (2004) identified the genes that respond to P deficiency and signaling cascades involved in plant responses to P deficiency. Early genes respond rapidly and often significantly to P deficiency and late genes impact on morphology, physiology or metabolism of plants upon prolonged P deficiency. Genes whose expression is altered by P deficiency include various transcription factors, which are thought to coordinate plant responses to P deficiency and other genes involved in P acquisition and tissue P economy.

Tara Singh and Nielsen (2004) conducted an experiment to assess the genetic variation in root properties (root morphology, including root hairs), mycorrhizal symbiosis, uptake kinetics parameters and root induced changes pH, organic acids and higher shoot biomass in barley genotype Salka than Zita which produced lower grain yields in P limited soils and they produced high grain yield only when P fertilizers was applied. They also reported entry of the phosphorous into roots mainly as H2PO4- via the soil solution. The concentration of H2PO4- in soil solution is pH related and plant species or genotypes induce rhizosphere acidification their by absorb more P by this mechanism.

Xiaolong Yan *et al* (2004) studied the two contrasting genotypes of soybean (*Glycine max* and *Glycine soja*), CN4 and XM6 and their 88 F_9-derived recombinant inbred lines (RILs) which were grown in a field with moderately low P availability. Some important root hair traits

including root hair density (RHD), average root hair length (ARHL) and root hair length per unit root (RHLUR) were investigated and quantified with an automatic image analysis system and the genetic variability for these root hair traits was estimated with the RIL population. The results indicated that the two parental genotypes differed significantly for three root hair traits. All the three root hair traits segregated in the RIL progenies with a normal distribution of the phenotypic values, indicating that these traits were possibly controlled by quantitative trait loci (QTLs) suggesting an important role of root hairs in P status.

Vidyarani *et al.* (2005) conducted a field experiment in Vertisol to find out genotypic response of 33 blackgram genotypes under three different P sources i.e., rock phosphate (RP), RP + phosphorus solubilizing bacteria (PSB) and single super phosphate. Sufficient variability was recorded in the material for root length, root dry weight, TDM, shoot dry weight, P uptake at 45 DAS in RP + PSB P-Source environment. Genotypes differed significantly at the time of harvesting for plant height, pod length, seed yield per plant and seed yield per line in SSP P-source environment. Correlation of P uptake at 45 DAS was positively significant with root dry weight, shoot dry weight and TDM at 45 DAS in all the P-source environments. Path analysis across different P-sources indicated differential path of productivity particularly under P stress condition. Wherein pod length had high direct contribution on seed yield per plant compared to harvest index under RP + PSB and SSP source environments, suggesting that application of phosphorus significantly increased yield under different P sources.

Devaiah (2007) elucidated the role of transcription factor WRKY75 in regulating adaptive mechanism during Pi deprivation. Suppression of WRKY75 through RNAi silencing resulted in early accumulation of anthocyanin, indicating that RNAi plants were more susceptible to P stress. Further, they revealed that expression of several genes involved in Pi starvation response including phosphatases. The expression of Mt4/TPS1 like genes were decreased when WRKY75 was suppressed. But, later it was found that regulatory effect of WRKY75 on root architecture could be independent of Pi status of the plant. Together, these results suggest that WRKY75 is a modulator of Pi starvation responses as well as root development and involved in regulating a nutrient starvation response and root development.

Hernandez *et al* (2007) investigated gene expression and metabolic responses of bean plants grown under P-deficient and P-sufficient conditions. P-deficient plants showed enhanced root to shoot ratio accompanied by reduced leaf area and net photosynthesis rates. A total of 126 genes, representing different functional categories, showed significant differential expression in response to P; 62% of these were induced in P-deficient roots. A set of 372 bean transcription factor (TF) genes, coding for proteins with Inter-Pro domains characteristic or diagnostic for TF were identified, 17 TF genes were differentially expressed in P-deficient roots; four TF genes, including MYB TFs, were induced. Stress-related metabolites such as polyols accumulated in P-deficient roots as well as sugars, which are known to be essential for P stress gene induction. Candidate genes have been identified that may contribute to root adaptation to P deficiency.

2.1.4 Adaptation of plants to low P availability

Low available P conditions are known to be for expression of an array of plant traits contributing to high P uptake efficiencies, among them are acidification of rhizosphere (i.e. excretion of protons from roots) and exudation of organic anions by roots (Randall, 1995) and also P absorption can be enhanced by increasing surface area of root system.

Capacity of plants to access P under limiting conditions depends on important adaptive traits, including organic acid excretion, alteration of pH of rhizosphere and increased ability to explore different layers of soil. (Schachtmn *et al.,* 1998, LopezBucio *et al,* 2000,. Plants evolved a diverse array of strategies to obtain adequate P under limiting conditions including modifications to root architecture, carbon metabolism and membrane integrity changes, exudation of low molecular weight (LMW) organic acids, protons and enzymes and enhanced expression of-numerous genes involved in low P adaptation.

Increased root surface area

Root length, radius, surface area, root to shoot dry weight ratio and root hair density are important morphological parameters of root for uptake of any nutrient and also for P. These root characteristics may be affected by soil properties (Prummel, 1979). The greater contribution of root hairs to P uptake is partly due to their surface area, which is similar to that of root cylinder. However, the main reason for high uptake efficiency of root hairs was their small radius and their perpendicular growth into the soil form the root axis. Because of the small radius compared to root axes, P concentration at root hair surfaces decreased at a slower pace and therefore P influx remains higher. The main reasons for differences found in P response among species were the size of root and number and length of root hairs. In a soil, hairs were able to satisfy a higher proportion of their P demand required for maximum growth.

Significant differences in root surface area of field grown maize genotypes positively correlated with shoot and root matter yield at flowering stage (Schenk and Barbar, 1980).

It was observed in tomato cultivars (Itoh and Barber, 1983) that P uptake efficiency was influenced by the amount of root surface per plant, rate of P uptake, kinetics of roots in addition to root hairs. In a similar study by Foehse and Jungk (1988) it was found that root hair length was closely related to the P content of the root and shoot but formation of root hairs did not depend directly on P concentration at the root surface but on the P content of the plant. It was found that under different conditions, contribution to P uptake by root hairs was upto 90 per cent of total uptake as revealed by the study of Foechse *et al.* (1991).

Bates *et al.* (1996) determined the efficiency of root hairs in phosphorous acquisition at low and high P availability. They observed that under higher P availability root hairs did not have any effect on plant P uptake and plant P content of three-week-old *Arabidospsis*. Under low P availability, wild type Arabidopsis had greater total root surface area and high P per unit length. He concluded response of root hairs to low P availability is an efficient strategy for P acquisition.

Bates *et al.* (2000) observed Arabidopsis root hairs grow longer and denser in response to low P availability. At low P, all plants were small and showed severe P stress symptoms. They concluded that the responses of increased root hair growth under low P availability is important in increasing P acquisition under low P conditions.

Root exudation of organic acids

Among eight annual pasture species grown in solution culture with very low P (0.04 μM P_i), lupins alone with large reserves of P in the seed could grow better (Asher and Lonergan, 1967).

The leakage of organic compounds from roots is a universal phenomenon (Rovira, 1969). Organic acid metabolism is of recent metabolism of fundamental importance at the cellular level for several biochemical pathways including energy production, formation of precursors for amino acid biosynthesis and at the whole plant level in modulating to environment. The composition of organic acids that accumulate depending upon species, age of plant and tissue type. Organic acids have a potential role as metabolically active solutes for the osmotic adjustment and the balance of cationic excess.

As far as the factors affecting the stimulation of exudates under P starvation, Ratnayake *et al* (1978) suggested that the decrease in membrane permeability was associated with the decrease in the level of phospholipids, resulting in a greater net leakage of amino acids and reducing sugars from the roots of sudan grass and Brazilian sour orange. Graham *et al* (1981) measured the root membrane permeability and concluded that increase in exudation of amino acids and reducing sugars from the roots was associated with change in the membrane permeability rather than the changes in root content of amino acids or reducing sugars. However there are few comparable evidences in the exudate compounds and factors affecting root exudation among leguminous crops under P starvation.

It is considered that root secretions contribute to the formation an important adaptive mechanism to phosphorus starvation, by which the plant can alter its microenvironment and subsequently affect phosphate availability in the rhizosphere. Gardner and Parbery (1983) reported that proteiod roots of P deficient lupin plants secrete a large quantity of citric acid and they suggest that large amount of inorganic phosphate is released from insoluble phosphate ferric hydroxide by the addition of varying amounts of citrate.

Recently several studies of root exudation have been focused on the interrelationship with phosphorus nutrition. It has been frequently reported that organic acids, one of the major components in the exudates dissolving organic phosphorus. Stimulation of exudation of citrate under phosphorus starvation in alfalfa was reported using an apparatus designed for the aseptic collection of root exudates (Lipton *et al.*, 1987). Organic acid excretion, which is thought to be a component of phosphate starvation rescue system in higher plants, is known to improve P acquisition from Aluminum phosphate (Gardner *et al.,* 1981, Lipton *et al.,* 1987).

Ellis Hoffland *et al.* (1989) conducted an experiment to identify the local rhizosphere acidification by rape as a reaction to P starvation was visualized by means of an agar plate technique. No differences in uptake rates of K-, NO^{3-} and Ca-ions could be detected between P starved and P-supplied plants. However, exudation of malic and citric acid was distinctly higher in acidified root zones of P starved plants, coinciding with higher levels of malate in the corresponding root tissue. Organic acid exudation is indicated as the cause of local rhizosphere acidification by rape as a reaction to P starvation and as a possible mechanism of its phosphate solubilizing capacity.

The ability of pigoenpea to utilize iron bound phosphorus was attributed to the presence of piscidic acid in the root exudates (Ae *et al,* 1990a,). Gardner *et al.* (1983) reported citric acid exuded from P starved proteoid roots of lupin reacted with ferricphosphate in the soil, then P was released by reduction of Fe^{3+} to Fe^{2+}.

Yasminali *et al* (1992) while determining the amount of composition of carboxylic acids in the root exudates and tissue extracts of leguminous crop plant subjected to P starvation for three days in water culture detected malonic, succinic, fumaric, malic, citric and t-aconitic acids. They also found that a large amount of these carboxylic acids, especially citric and malic acids were exuded from the roots of chickpea as compared with these of soybean kidney bean, cowpea and pigeon pea. The large amount of carboxylic acids observed in exudates of chickpea roots could not be directly correlated to the content of phospholipids in the roots.

Jane *et al.* (1994) studied proteoid roots development in *Lupinus albus* L. in response to nutrient stress especially phosphorus. Proteoid roots excrete citrate they evaluated in vitro enzyme activities of citrate synthesis (CS), malate dehydrogenase (MDH) and phosphoenol pyruvate carboxylase (PEPC) in proteoid and normal roots of plants grown with or without P. The in vitro specific activities of CS, MDH and PEPC of analysis showed the PEPC enzyme protein was highly expressed in -P proteoid roots compared to other tissues. The majority of the fixed ^{14}C was found in organic acids, predominantly malate and citrate. Respiration rate of proteoid roots were 31 per cent less than those normal roots. This experiment provide an evidence for increased synthesis of citrate in proteoid roots compared to normal roots and single superphosphate (SSP). They reported that genotypes varied widely for P uptake values under different sources of P nutrition.

Bhupinder Singh and Renu Pandey (2002) examined two maize genotypes raised under P deficient condition. The genotype showed differences in magnitude of root exudation and its sugar and amino acid content. Genotypic differences were also observed for P uptake using ^{32}P. Uptake efficiency of the genotypes was positively related to exudation levels of roots. Brewesten *et al* (1976a) demonstrated that rape plants, which have fine roots and abundant root hairs, increased in lengths and number at decreasing P supply. P uptake by rape in soils poor in P was higher than expected on the basis of P movement to enlarged root surface (Brewsten *et al.,* 1976b).

Yi-Dan Li *et al.* (2005) conducted an experiment for QTL mapping of P deficiency tolerance in soybean. In their study, they used 184 recombinant inbred line (RIL) families

developed from soybean varieties Kefeng No. 1 and Nanong 1138-2 which were used to identify QTL associated with P deficiency tolerance. Seven traits of plant height (HT), weight of fresh shoot (FSW), weight of fresh root (FRW), weight of dry root (DRW) and length of main root (RL) were used as parameters to assess the P deficiency tolerance. The QTLs that had LOD scores more than three were detected for all the three traits above. Most of the QTL explained more than 10 per cent of total variation. The two QTLs for P content in leaf explained more than 20 per cent of the total variation, respectively five QTLs were mapped on linkage group F_2 and two on linkage F_1. It was suggested that genes related to P deficiency tolerance located on linkage group F in soybean.

2.2 Correlation studies

Correlation study indicates the degree of interdependence of plant characters, which is an important tool in selection of a pertinent genotype. Therefore, information on association between characters is quite useful to plant breeders to formulate their breeding and selection strategies.

Lindgren *et al*. (1977) while evaluating 59 lines of *Phaseolus vulgaris* for differences in rates of P absorption noticed that P absorption rate was negatively correlated with root dry weight.

Misra (1983) observed that the pods per plant, clusters per plant and days to maturity had high positive correlation with yield at both genotypic and phenotypic levels in blackgram.

Ramprasad *et al*. (1989) conducted a study with 14 entries (segregating material of blackgram) and indicated that branches per plant and 100-seed weight had high genotypic direct effects on seed yield though their association with yield was very low and non-significant. Along with these two characters, pods per plant appeared to be the most important yield contributing component of blackgram.

Bass and Beusichem (1990) noticed highest correlation between shoot biomass and the total P concentration among the inbred lines from three populations of *Plantago major* L.

Positive and significant correlation of seed yield was recorded with 100 seed weight, number of days to maturity, number of primary branches per plant and plant height both at genotypic and phenotypic levels by Verma (1992) among different genotypes of blackgram.

Ranganayaki and Sreerangaswamy (1992) reported high variability for plant height with high heritability, high variability for number of branches per plant with moderate heritability and GA, low variability for pod length with moderate GA, low variability for number of seeds per pod with high heritability and low GA, high variability for seed yield per plant with high heritability and GA, high variability for TDM with high heritability and GA in blackgram.

Yan *et al*. (1995a) recorded significant correlation of seed weight with shoot biomass both at low and medium soil P levels in common bean. Shoot biomass was correlated with P in nearly all cases. The correlation of P accumulation with either seed weight or seed P was highly significant at low P levels and in most cases at medium levels.

Singh (1998) noticed that grain yield was positively correlated with pods per plant, seeds per pod and 100 seed weight and negatively correlated with days to flowering, days to maturity and plant height in blackgram.

Bhagowati and Hazarika (2001) studied the trend of character association in two crosses of blackgram advanced from F_2 to F_4. A stable trend of positive correlation of seed yield with plant height, pod number and harvest index was observed.

Character association analysis in fifty genetically diverse genotypes of blackgram revealed significant positive association of biological yield per plant, pods per plant, clusters per plant, branches per plant, plant height, harvest index and days to maturity with seed yield in decreasing order of magnitude (Sagar and Sekhar, 2001).

Bruck *et al*. (2003) observed genotypic variation for root length density (RLD) and root length (RL) among eight pearl millet varieties. Root length and shoot dry matter were directly correlated over P supplies. They also observed that response of root fraction to variation was more at low productivity soil (40%) than in high productivity soil (20%) and suggested to use shoot parameters for selection as an indirect method for selection of root traits as genotypes exhibited high variability for the root traits.

Roopalakshmi *et al.* (2003) studied phenotypic correlation of seed yield with its component traits in four selected single cross F_2, corresponding F_2M_2, two three way and one double cross F_2 populations of blackgran. All the eleven populations exhibited significant positive correlation of plant height, number of cluster and pods per plant with seed yield per plant except two F_2M_2 populations for plant height. In the irradiated populations, the magnitude of the association of plant height with seed yield was of lower order compared to other F_2 populations. Irradiated population of single cross, TAU-1 $\times$ 169 exhibited significant correlation between pod length and number of pods per plant which was changed from negative to positive consequent to irradiation. Most of the traits under study including pod length contributed towards seed yield per plant in single cross F_2 and F_2 M_2 and double cross populations.

Revanappa *et al.* (2005) conducted an experiment using 29 advanced breeding lines and two check varieties, which were raised over three environments to study the correlation among eight different quantitative traits and to carry out path coefficient analysis for seed yield and seed yield per plant exhibited positive significant association with cluster per plant and pods per plant. Similarly clusters per plant with pods per plant also exhibited positive significant associations which were quite consistent over environments. The path coefficient analysis revealed that pods per plant and pod length had high direct contribution to seed yield per plant, whereas number of clusters per plant had indirect contributes via pods per plant at all the three test environments. These test weight exhibited significant association with seed yield only at location where blackgram is cultivated as traditional crop.

2.3 Path coefficient analysis

Seed yield and various structural and growth components of plants may share linear correlations which may present a confusing picture. Path analysis helps to resolve the correlation coefficients by indicating the direct and indirect effect of various components on seed yield. The technique of path coefficient analysis was developed by Wright (1921) and is still considered as a valuable tool in detecting the real merits of characters contributing yield.

Rani and Rao (1981) reported that number of pods per plant, 100 seed weight, and number of seeds per pod showed high positive association with seed yield and they also had direct effect on seed yield. Pod weight and pod length were highly correlated with yield but had high negative direct effects. They concluded that selection should be based on large seeds, more number of pods per plant and more number of seeds per pod.

Patel and Shah (1982) showed that clusters per plant followed by pods per plant had maximum positive direct effects on seed yield.

Misra (1983) showed that pods per plant had the largest positive direct effect but its indirect effect via other characters was very small, 100-seed weight had moderate positive effect and seeds per pod had moderate negative direct effect. Thus pods per plant may be considered as most important character for selection of genotypes with high yield.

A study made by Rao and Suryawanshi (1988) with 46 genotypes of blackgram under two environments revealed that pods per plant, seeds per pod, pod length and 100-seed weight were the most important selection criteria for yield improvement in both the environments.

Parameshwarappa (1989) conducted path analysis with 226 genotypes of blackgram and reported that days to 50 per cent flowering, days to maturity, plant height, biological yield per plant and harvest index could prove to be the best criteria for improving yield in summer.

In *kharif*, number of primary branches per plant, clusters per plant, pod length and harvest index may prove to be the best criteria for yield improvement.

Ramprasad *et al*. (1989) conducted a study with 14 entries (segregating material of blackgram) and indicated that branches per plant and 100-seed weight had high genotypic direct effects on seed yield though their associations with seed yield were very low and non-significant. Along with these two characters, pods per plant appeared to be the most important yield contributing component of blackgram.

A study was made by Ranganayaki and Sreerangaswamy (1992) with 20 genotypes of blackgram. Path coefficient analysis revealed that plant height exerted maximum direct effect on yield followed by 100 seed weight and maximum negative direct effect on seed yield was contributed by peduncle length. The residual effect was 0.46 indicating that some important components contributing to the seed yield had not been included in the study.

Patil (1996) evaluated 196 genotypes for genetic variation for morpho-physiological traits influencing seed yield in blackgram. TDM at 75 DAS was found to had maximum direct effect on seed yield.

Shrivastava and Saichan (1996) carried out path coefficient analysis involving seven parents and 21 hybrids and the results revealed that pods per plant and seeds per pod were common factors influencing seed yield, biological yield and harvest index.

Inderjit Singh and Singh (1998) involving 16 genotypes of blackgram indicated that number of seeds per pod and 100 seed weight exerted a high positive direct effect on grain yield per plant. Days to flower, days to maturity, plant height and number of pods per plant had a negative direct effect on yield, but plant height and number of pods per plant had an indirect positive effect through number of seeds per pod and 100-seed weight with grain yield.

Natarajan and Rathinasamy (1999) evaluated fifteen parents and 50 hybrids of blackgram and reported that pods per plant exerted positive direct effect on yield.

Pariya *et al*. (1999) analysed 70 diverse genotypes of blackgram for path analysis and noticed that pods per plant, plant height and 100-seed weight had direct effect on yield. Thus maximum emphasis for selection of better genotypes should be given to pods per plant, plant height and 100-seed weight.

Path analysis (Isaacs *et al*., 2000) involving 32 genotypes of blackgram revealed that the number of seeds per pod, 100-seed weight, number of branches per plant, harvest index and pod length exerted high positive direct effect on grain yield. Number of pods per plant and seed protein content recorded high negative direct effects on yield but number of pods per plant had high indirect effects through plant height, number of branches per plant and number of seeds per pod.

Nagarjuna and Reddi (2001) reported that biological yield per pant, harvest index and pods per plant had high direct effects on grain yield, whereas high indirect positive effects were shown by other traits through biological yield per plant, harvest index and pods per plant in blackgram.

Vaithiyalingan *et al*. (2002) carried out path analysis involving for 30 hybrids and 11 parents in blackgram. Dry matter production followed by pods per plant and harvest index had maximum direct effect on seed yield.

3. MATERIAL AND METHODS

Experiments to assess the genetic variability for P uptake in blackgram and to investigate the mechanisms adopted by different genotypes for high and low P uptake and the materials used and procedures adopted are given in this chapter.

3.1 Screening of genotypes for P uptake under different P availability conditions

3.2 Methods

3.3 Methodologies adopted

3.4 Biochemical study

3.5 Statistical analysis

3.1 Screening of blackgram genotypes for P uptake under different P availability conditions

Experimental details

3.1.1 Plant material

The blackgram genotypes for the present study were obtained from on going project on blackgram in the Department of Genetics and Plant Breeding, Agriculture College, Dharwad. The list of the genotypes used is given in Table 1.

3.1.2 Experimental site

The pot culture experiment using vermiculite as media under shade net (35%) was carried out during summer 2007 at Botany Garden, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad, which is located in the transitional belt of Karnataka state at $15^0$3 North latitude, $75^0$07' East longitude and at an altitude of 678 m above mean sea level with an average rainfall of about 800 mm.

3.2 Methods

3.2.1 Pot culture experiment

Experimental layout

Pot culture experiment was conducted by following the randomized block design (RBD) with 2 replications with P deficient and P sufficient condition during summer, 2007.

Seeds of different blackgram genotypes (given in Table 1) were sown in pots (10" x 10") containing 500 g of vermiculite as media. At the time of sowing, two good seeds were sown per pot. Fifty ml of distilled water was added to each pot on the date of sowing and further according to the different treatments of phosphorous, 30 ml of 50 per cent P and 100 per cent P of Hoagland's nutrient solution was added on the 2^{nd} and 3^{rd} day after of sowing. There was gap on the 4^{th} date of sowing. The Hogland solution was added till the 50 and 100 per cent requirement of P considering 0.5 kg as soil media.

3.2.2 Vermiculite properties

Genotypes were grown in vermiculite instead of soil to distinguish clear difference between genotypes for P uptake. The physical and chemical properties of vermiculite are given in Appendix – I.

3.2.3 Observations recorded

Observations were recorded at 45 days after sowing (DAS) and also at the time of harvest. At 45 DAS, two replications were randomly selected with 50% P and 100% P Hoglands solution application. The plants were carefully removed along with intact root system from pot and observations on root traits were recorded. The root and shoot was separated, shade dried and shoot dry and root dry weights were recorded.

3.2.4 Observation at 45 DAS

1. Plant height (cm): Plant height was measured from the ground level to tip of the main stem and is expressed in cm.

2. Root length (cm): The root length was measured from collar region to the tip of tap root and expressed in cm.

3. Lengthiest lateral root length (LLRL): Among the lateral roots, the lengthiest lateral root was measured and expressed in centimeter

4. Root volume (mm^3) : Root volume was measured as an amount of space occupied and it was calculated by using water displacement method i.e., the level of water raised in a container and was expressed in mm^3.

5. Root collar diameter (mm): The root collar diameter was measured by using vernier caliper scale and is expressed in mm.

6. Number of lateral roots : Number of lateral roots were recorded by manually counting the number of lateral roots.

7. Root dry weight (g) : Root dry weight signifies the amount of dry weight that is put fourth by the plant in different treatments and was recorded in gram.

8. Shoot dry weight (g) : Shoot dry weight signifies the amount of dry weight in gram that is put forth by the plant in different treatments and was recorded in gram.

9. Leaf area (cm^2) : After 45 DAS, the separated shoot was dried (not fully dried), leaves were taken to measure the leaf area by using instrument called CID leaf area meter and was expressed in cm^2.

10. Root surface area (mm^2) : After 45 DAS, the separated root portion was taken to measure the root surface area by using procedure (given under 3.3.5) and it was expressed in mm^2.

11. Root to shoot ratio : The ratio of root to shoot dry weight was calculated by dividing root dry weight with shoot dry weight.

12. Total P uptake (mg per plant) : The dried roots and shoot were mixed and then P content in root and shoot was estimated as percentage then calculated P uptake in mg/plant.

3.2.4 Observations at the time of harvesting

1. Number of pods per plant : Total number of pods per plant were recorded by counting the number of pods per plant.

2. Pod length (cm) : The pod length of two pods per plant was measured and it was expressed as average in centimeter (cm).

3. Number of seeds per pod : The number of seeds per pod were recorded by counting the number of seeds per pod.

4. Shoot dry weight (g) : It was recorded at the time of harvesting and expressed in gram.

5. Seed yield per plant : The seed weight from each pot is expressed in gram (g) as seed yield per plant.

6. Seed index : It is the weight of 25 seeds and expressed in gram

7. Harvest index : It is the ratio of seed yield to the biological yield per plant.

$$HI = \frac{\text{Seed yield/plant (g)}}{\text{Total biological yield/plant (g)}}$$

8. Shoot P uptake : The P content in shoot was estimated in percentage then calculated by per cent P x dry matter of shoot and expressed in mg per plant.

9. P content in seed : The P content of seed was estimated in percentage and then it is calculated by per cent P x dry seed weight and is expressed as mg per plant

10. Total P uptake (mg/plant) : It is the total amount of P contained in the plant (shoot and seed) and it was expressed in mg/plant.

3.3 Methodologies adopted

3.3.1 Preparation of Hoagland's solution

Reagents	Molar concentration	Aliquot taken
KNO_3	1 M	6 ml
KH_2PO_4	1 M	2 ml
Ca (NO_3) $4H_2O$	1 M	4 ml
$MgSO_4.7H_2O$	1 M	2 ml
KCl	1 M	2 ml
(micronutrient solution)		1 ml
H_3BO_3	2.86 g/1000 ml	
$MnCl_2$	1.81 g/1000 ml	
$ZnSO_4.7H_2O$	0.22 g/1000 ml	
$CuSO_4$	0.008 g/1000 ml	
H_2MoO_4	0.02 g/1000 ml	
FeEDTA		1 ml

3.3.3 Determination P in plant samples

The P content in leaf and root samples was estimated by following Vanadomolybdate method (Jackson, 1973). The samples were powdered in a pestle and mortar and 0.50 g sample was taken for wet digestion for the estimation of P. The sample was 1st pre-digested with 5 ml of concentrated nitric acid over night and then digested with 10 ml of triacid mixture containing concentrated nitric, sulphuric acid and perchloric acid in the ratio of 5:1:4.

The conical flask was kept on sand bath without shaking and allowed to digest until the contents were clear and while precipitate appeared the residue was cooled and dissolved in 6N HCl and finally the volume was made to 50 ml with distilled water.

3.3.4 Preparation of standard curve for estimation of P in plant samples

Reagents

1. Prepare 100 ppm of P standard stock solution by dissolving 0.2195 g of KH_2PO_4 (AR grade) in 400 ml of distilled water and make upto 500 ml.

2. HNO_3 – Vanadatemolybdate reagent

Dissolve 22.5 g of ammonium molybdate in 400 ml of distilled water warmed to about 50^{0}C. Dissolve 1.25 g of ammonium metavanadate in 300 ml of boiling distilled water. Add vanadate solution to cooled molybdate solution and cool to room temperature. Add 250 ml of concentrated HNO_3 and dilute to 1 litre with cool distilled water.

Procedure

Preparation of standard curve

Prepare 0.5, 1, 2, 3, 5, 7, 10, 12, 15, 18 and 20 ppm P working standard solution by pipetting out 0.25, 0.5, 1.0, 1.5, 2.5, 3.5, 5.0, 6.0, 7.5, 9.0 and 10 ml of stock P solution respectively into 50 ml volumetric flasks separately. Add to each 10 ml of vanadatemolybdate reagent and make up the volume to 50 ml with distilled water and shake. Allow to stand for 30 minutes and yellow colour will be developed and intensity of colour was recorded at 470 nm wavelength. Then using optical densities graph was plotted against concentration and standard graph was obtained.

Sample

a) Digested sample of 5 ml was taken in a 50 ml volumetric flask and 10ml of HNO_3 Vanadomolybdate was added and volume was made up to 50 ml.

b) After 30 min the intensity of colour was recorded at 470 nm using (UIV) spectrophotometer.

c) Concentration of P was found out by referring to standard curve.

Calculation

The per cent phosphorous was calculated by following formula.

$$\% P = \frac{\text{Graph (ppm)}}{10^3 \times 10^3} \times \frac{\text{Volume of digested sample}}{\text{Weight of sample}} \times \frac{\text{Vol. made}}{\text{Aliquot of digest taken}} \times 100$$

3.3.5 Estimation of root surface area

Root surface area exposed to inert material was measured by the Nitrite assay. The air dried fresh roots of blackgram genotypes were dipped for 5 seconds in a beaker containing 15 mM $NaNO_2$ solution. Roots were lifted from the beaker and again roots were air dried for 30 minutes. Then the roots were again immersed in beaker containing 25 ml distilled water for sufficient time (20 mm). The Nitrite ions adhering to root surface will go into distilled water. The nitrite present in the distilled water was estimated using spectrophotometer.

3.3.6 Preparation of standard curve

Pieces of graph paper of known area (100 mm^2, 200 mm^2, 400 mm^2, 600 mm^2, 800 mm^2 and 1000 mm^2) were dipped into beaker containing 15 mM $NaNO_2$ solution for 15 seconds and care was taken for proper immersion of paper pieces into the solution.

Then the paper pieces were air dried for 10 min and later they were dipped into beaker containing 25 ml distilled water. The nitrite present in respective beakers was measured colorimetrically through spectrophotometer as follows.

One ml of aliquot from beakers was taken into a 10 ml test tubes and one ml of 0.1 per cent sulphanalamide (in 1.5 N HCl) and 1 ml of 1 per cent NEDD was added for colour development and the volume was made upto 4 ml using distilled water. The colour read at 430 nm using spectrophotometer. To estimate sample nitrite content, one ml of aliquot taken from samples and all the reagents mentioned were added and reading was taken by the standard graph.

3.4 Biochemical study

3.4.1 Vermiculite solution culture experiment for organic acid estimation

The following experiment was conducted to know the biochemical adaptation under P deficiency. Root exudes were collected from different genotypes to find out which organic acid was secreted from roots of different genotypes in blackgram when grown under P deficient condition.

This experiment was conducted in green house, at Botany Garden, University of Agricultural Sciences, Dharwad. Seeds were sown in plastic pot (10" x 10") containing 250 g of vermiculite by providing with Hoagland's (50% P and 100% P) nutrient solution. After 15 days of sowing, seedlings were transferred to test tubes (covered by a thick black paper to avoid direct sunlight) containing 50 per cent P and 100 per cent P of a Hoagland's nutrient solution. The solution was given at 3 days interval to maintaining normal growth of the plant. After 30 days lechates from test tubes was collected for the organic acid estimation.

3.4.2 Procedure of organic acid

1. Concentration of leachates were reduced to $1/10^{th}$ by keeping in water bath at 60^0C
2. Preparation pure organic standards as 20 mg/ml stocks
3. Spot 10 micro litre of standard organic acid and 15 m litre of concentrated supernatant (filtered in Watman No.1) on chromatography paper or TLC plate and dry.
4. Run chromatogram using N-butanol, acetic acid and water in 12:3:5 ratio.
5. Air dry the chromatogram and spray with 0.04 per cent BCG (Bromocrasal green) (40 mg in 100 ml methanol –pH-7).
6. Record the RF values
7. Yellow spots on Blue background

The concentrated solution was spotted on TLC plate, including our interest of organic acid (root exudes), some standard organic acids were spotted on same TLC plate. In low P (deficient) and high P (sufficient) levels both oxalic acid and citric acid were secreted.

3.4.3 Relative front (RF) values of organic acids

RF values of these organic acids were worked out in both phosphorus levels and RF values of each organic acid was recorded by using the formula.

$$RF = \frac{\text{Solvent front}}{\text{Solute front}}$$

3.5 Statistical analysis

Data collected on individual plants of each genotype at each replication was used to calculate mean, range, genetic parameters, correlation analysis and path analysis as given below.

3.5.1 Mean and range

i) Mean ($\bar{X}$) = $\frac{\text{Sum of observations of all the plants}}{\text{Number of plants}}$

ii) Range = The minimum and maximum values for each trait

3.5.2 Analysis of variance (ANOVA)

The analysis of variance (ANOVA) for all characters was carried for 12 characters at 45 DAS and 10 character at the time of harvesting. The model of analysis of variance is given below.

The structure of ANOVA

Sl. No.	Source of variation	DF	M.S.S.	Expected M.S.S.
1	Replication	r-1	M_1	-
2	Genotype	g-1	M_2	$\sigma^2e + \sigma^2g$
3	Error	(r-1)(g-1)	M_3	σ^2e
	Total	rg-1	$M_1+M_2+M_3$	

3.5.2.1 Estimation of genetic parameters

In order to assess and quantify the genetic variability among the genotypes for twenty characters, the following parameters were estimated.

i) Estimation of variance components

Phenotypic and genotypic variances were estimated using the following formula,

$$\text{Genotypic variance } (\sigma_g^2) = \frac{\text{MSS (genotypes) - MSS (error)}}{\text{Number of replications}} = \frac{M_2 - M_3}{r}$$

$$\text{Phenotypic variance } (\sigma_p^2) = \sigma_g^2 + \text{MSS error} = \frac{M_2 - M_3}{r} + M_3$$

<

ii) Coefficient of variability

Both genotypic and phenotypic coefficients of variability were computed as per the method suggested by Burton and Devane (1953).

a. Genotypic coefficient of variability (GCV)

$$GCV\ (\%) = \frac{\sigma_g}{\bar{X}} \times 100$$

b. Phenotypic coefficient of variability (PCV)

$$PCV(\%) = \frac{\sigma_p}{\bar{X}} \times 100$$

Where,

σ_g = Genotypic standard deviation

σ_p = Phenotypic standard deviation

$\bar{X}$ = General mean of the character

GCV and PCV values were categorized as low, moderate and high values as suggested by Sivasubramanian and Menon (1973), which is as follows.

0-10% : Low

10-20% : Moderate

20% and above : High

iii) Heritability (h^2)

Heritability in broad sense was computed as the ratio of genetic variance to the total phenotypic variance as suggested by Hanson *et al*. (1956) and expressed as percentage.

$$\text{Heritability } (h^2) = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

Where,

σ_g^2 = Genotypic variance

σ_p^2 = Phenotypic variance

The heritability percentage was categorized as low, moderate and high as given by Robinson *et al*. (1949).

0-30% : Low

30-60% : Moderate

60% and above : High

iv) Genetic advance (GA)

Genetic advance was estimated by using the formula given by Johnson *et al*. (1955).

$$GA = h^2 k \sigma_p$$

Where,

h^2 = Heritability in broad sense

k = Selection differential which is equal to 2.06 at 5% intensity of selection (Lush, 1949)

σ_p = Phenotypic standard deviation

v) Genetic advance as per cent of mean (GAM)

$$\text{GAM (\%)} = \frac{GA}{\bar{X}} \times 100$$

Where,

GA= Genetic advance

$\bar{X}$ = General mean of the character

Genetic advance as per cent mean was categorized as low, moderate and high as given by Johnson *et al*. (1955).

It is as follows.

0-10% : Low

10-20% : Moderate

20% and above: High

3.5.3 Correlation analysis

The correlation coefficients were worked out to determine the degree of association of a character with yield and also among the yield components.

Phenotypic correlations were computed by using the formula given by Weber and Moorthi (1952).

$$r_p = \frac{\text{Cov } XY_p}{\sqrt{X^2_p \times Y^2_p}}$$

Where,

r_p = Phenotypic correlation

Cov XY_p = Phenotypic covariance between the characters 'x' and 'y'

X^2_p and Y^2_p = Phenotypic variance of the characters 'x' and 'y' respectively.

Phenotypic correlation coefficients were compared against r values given in Fisher and Yates (1963) Table at (n-2) degrees of freedom at the probability levels of 0.05 and 0.01 to test their significance.

3.5.4 Path analysis

Path analysis was carried out by using both phenotypic and genotypic correlation coefficients to know the direct and indirect effects of the components on yield as suggested by Wright (1921) and illustrated by Dewey and Lu (1959).

Path coefficients were obtained by solving the simultaneous equations, which express the basic relationship between correlations and path coefficients. The equations are as follows :

$$r_{1.y} = P_{1y} + r_{1.2} P_{2y} + r_{1.3} P_{3y} + \ldots\ldots\ldots + r_{1.k} P_{ky}$$

$$r_{2.y} = r_{2.1} P_{1y} + P_{2y} + r_{2.3} P_{3y} + \ldots\ldots\ldots + r_{2.k} P_{ky}$$

...

...

$$r_{k-1.y} = r_{k-1.1} P_{1y} + r_{k-1.2} P_{2y} + r_{k-1.3} P_{3y} + \ldots\ldots\ldots + P_{k-1y}$$

Where, $r_{1.y}$ to $r_{k-1.y}$ denote the correlation coefficients between independent characters 1 to k-1 and dependent character 'y', $r_{1.2}$ to $r_{k-2.k-1}$ denote the correlation coefficients between all possible combinations of independent characters. P_{1y} to P_{k-1y} denote the direct effects of characters 1 to k-1 on character y.

Table 1: List of blackgram genotypes used in the study

Sl. No.	Genotypes
1	DBS – 7
2	DBS – 8
3	DBS – 13
4	DBS – 14
5	DBS – 21
6	DBS – 22
7	DBS – 24
8	DBS – 25
9	Northern Eastern line
10	7581 – 7
11	G – 1
12	447 – 2
13	134PLU-495
14	ER SEL-495
15	797/KC- 148
16	570-152
17	119PLU-283
18	335

4. EXPERIMENTAL RESULTS

An experiment was conducted to identify the genetic variability among 18 blackgram genotypes for phosphorous uptake, its utilization efficiency and to examine the mechanism involved in phosphorous uptake under varying P availability. Eighteen blackgram genotypes were grown in deficient (50% P) and sufficient (100% P) conditions upto 45 DAS and time of harvesting for making observations on root and shoot morphology and seed yield and its components respectively apart from P uptake. The experimental results are presented under the following headings.

4.1 Analysis of variance

4.2 Correlation studies

4.3 Path coefficient analysis

4.4 Biochemical study

4.1 Analysis of variance

The analysis of variance was carried out for 18 genotypes at 45 days under P deficient condition and in sufficient P conditions. The variance due to known and unknown causes were worked out using the method suggested by Choudhary and Prasad (1967) and Lush (1949) and the results are presented in Table 2 and 3.

As evident from the Table 2 and 3 the genotypes differed significantly at 45 DAS for all characters exhibiting significant differences except plant height and root collar diameter which exhibited at 5 per cent level of probability under deficient P condition. In sufficient condition all characters exhibited highly significant differences, except lengthiest lateral root which exhibited significant difference only at 5 per cent level of probability.

At the time of harvesting all characters under study showed highly significant difference in both deficient and sufficient P condition but number of pods per plant exhibited only significant difference in deficient P condition.

4.1.2 Analysis of variance for root and shoot morphological and P uptake traits at 45 DAS

4.1.2.1 Plant height (cm)

The mean, range, phenotypic and genotypic coefficients of variability, heritability and genetic advances over mean for the 12 characters studied are presented in Table 4

In P deficient condition the average plant height was 8.52 cm and genotypic mean values ranged from 6.80 cm (7581-2) to 11.4 cm (447-2). The genotypic coefficient of variability (12.24%) and phenotypic coefficient of variability (14.64%) were moderate with a high heritability (69.9%) and high GAM (21.12%) values.

In sufficient P condition the average plant height was 9.74 cm and genotypic mean values ranged from 8.12 cm (NE) to 13.90 cm (447-2). The estimates of PCV (14.39%) and GCV (13.03%) were moderate. The heritability estimate was high (82.0%) with high GAM of 24.33 per cent.

4.1.2.2 Root length (cm)

Average root length in P deficient conditions was 17.63 cm and mean ranged from 13.90 cm (335) to 21.40 cm (DBS-22) with a moderate genotypic (10.25%) and phenotypic (11.92%) coefficient of variation and it exhibited high heritability (74.0%) with a moderate GAM of 18.15 per cent for this trait.

Table 2: Analysis of variance of root and shoot morphological traits towards phosphorus uptake under P deficient and P sufficient condition at 45 DAS in blackgram

Sl. No	Character	Phosphorus level	GMSS	EMSS
1	Plant height (cm)	50% P 100% P	2.6471* 3.5816**	0.4691 0.3533
2	Root length (cm)	50% P 100% P	7.6812** 14.044**	1.1478 0.8071
3	Lengthiest lateral root length (cm) (LLRL)	50% P 100% P	3.8459** 14.1211**	1.1603 1.0707
4	Root volume (mm^3)	50% P 100% P	1.0547** 0.9934*	0.2296 0.3529
5	Root collar diameter (mm)	50% P 100% P	0.0017* 0.0013**	0.0007 0.0003
6	Number of lateral roots	50% P 100% P	2.6066** 1.3794**	0.5902 0.4187
7	Root dry weight (g)	50% P 100% P	0.0008** 0.0016**	0.5377 0.0001
8	Shoot dry weight (g)	50% P 100% P	0.0134** 0.0281**	0.0003 0.0001
9	Leaf area (cm^2)	50% P 100% P	319.6** 498.54**	3.7773 10.793
10	Root surface area (mm^2)	50% P 100% P	99744** 10263**	24246 15631
11	Root to shoot ratio	50% P 100% P	0.0110** 0.0129**	0.0005 0.0002
12	Total P uptake (mg/plant)	50% P 100% P	0.1114** 0.1489**	0.0026 0.0079

* - Significant at 5% level of probability

** - Significant at 1% level of probability

In sufficient condition average root length was 21.21 cm and mean values ranged from 17.05 cm (113PLU-495) to 26.00 cm (335). The phenotypic and genotypic coefficient of variability were moderately 12.85 per cent and 12.13 per cent respectively. It exhibited high heritability estimates of 89.1 per cent with high GAM of 23.57 per cent.

4.1.2.3 Lengthiest lateral root length (cm) (LLRL)

Average lengthiest lateral root length in deficient P condition was 15.32 cm and mean ranged from 11.65 cm (7581-2) to 17.55 cm (119 PLU-283). There was low genotypic (7.56%) and moderate phenotypic (10.32%) coefficients of variation. This trait showed a moderate heritability (53.6%) with moderate GAM (11.43%).

In sufficient condition average of this trait was 17.05 cm and mean ranged from 13.25 cm (DBS-21) to 22.65 cm (ER.SEL495). The GCV (15.74%) and PCV (22.83%) estimates were moderate. The heritability was low (47.6%) with high GAM of 22.28%.

4.1.2.4 Root volume (mm^3)

The genotypic mean root volume recorded was 2.31 mm^3 with range of 1.35 mm^3 (335) to 3.60 mm^3 (DBS-22). The phenotypic and genotypic coefficient of variability were high 34.55 and 27.69 per cent respectively. The heritability estimates was high 64.2 per cent with high GAM of 45.88 per cent under deficient P condition.

Average for this trait recorded was 3.59 mm^3 and mean ranged from 2.50 mm^3 (335) to 4.50 mm^3 (DBS-14). The GCV and PCV estimates were moderate (15.74%) and high (22.83%) respectively. The heritability estimate was moderate (47.6%) with high GAM of 22.28 per cent under sufficient P condition.

4.1.2.5 Root collar diameter (mm)

In deficient condition average root collar diameter was 0.21 mm and mean ranged from 0.14 (DBS-21) to 0.27 (447-2). The estimates of GCV (10.80%) and PCV (16.26%) were moderate. The heritability estimate was low 39.2 per cent with moderate GAM of 14.28 per cent.

4.1.2.6 Number of lateral roots

Genotypes differed significantly for production of number of lateral roots under deficient condition with average of 6.54 and mean ranged from 4.00 (7581-7) to 8.25 (DBS-25). The estimates of PCV (15.35%) and GCV (19.33%) were moderate. The estimates of heritability was high 63.10 per cent with high GAM of 24.92 per cent.

Average of this character was 5.31 and mean ranged from 3.75 (DBS-7) to 6.77 (DBS-13). The estimates of PCV (17.83%) and GCV (13.03%) were moderate. The heritability estimates was moderate (53.4%) with GAM of 19.58 per cent in sufficient condition.

4.1.2.7 Root dry weight (g)

Average of root dry weight was 0.18 g and mean ranged from 0.15 g (335) to 0.22 (DBS-8). The estimates of PCV (11.37%) and GCV (10.68%) were moderate and estimates of heritability was high (88.4%) with high GAM of 22.22 per cent in deficient condition.

Overall mean root dry weight was 0.14 g and mean values ranged from 0.1 g (DBS-24) to 0.22 g (DSB-7). The estimates of PCV was high (20.96%) and GCV was high (19.10%). The heritability estimates was 83.1 per cent with high GAM of 35.71 per cent under sufficient P condition.

4.1.2.8 Shoot dry weight (g)

Average for this trait was 0.36 g and genotypic mean values ranged between 0.26 g (DBS-24) to 0.51 g (DBS-22). There was high coefficients of variability at phenotypic

Table 3: Analysis of variance of seed yield and its component and phosphorus uptake under P deficient and P sufficient condition at the time of harvesting in blackgram

Sl. No	Character	Phosphorus level	GMSS	EMSS
1	Number of pods/plant	50% P 100% P	0.7095* 1.6655**	0.2324 0.3302
2	Pod length (cm)	50% P 100% P	0.2307** 0.2797**	0.0662 0.0577
3	Number of seeds/pod	50% P 100% P	0.5424* 0.5183**	0.1846 0.1392
4	Shoot dry weight (g)	50% P 100% P	0.0160** 0.0126**	0.0005 0.0001
5	Seed yield (g)	50% P 100% P	0.1455** 0.0335**	0.0001 0.0008
6	Seed index (g)	50% P 100% P	0.0553** 0.1517**	0.0107 1.4358
7	Harvest index	50% P 100% P	0.0132** 0.0055**	0.0003 0.0001
8	Shoot P uptake (mg/plant)	50% P 100% P	0.0351** 0.1987**	0.0015 0.0024
9	Seed P uptake (mg/plant)	50% P 100% P	0.4245** 1.0856**	0.0059 0.0137
10	Total P uptake (mg/plant)	50% P 100% P	0.4490** 3.1369**	0.0060 0.0166

* - Significant at 5% level of probability

** - Significant at 1% level of probability

(22.52%) and genotypic (21.97%) levels. Heritability value was high (95.1%) with a high GAM of 44.44% in deficient condition.

In sufficient condition average shoot dry weight was 0.43 g and mean value ranged from 0.21 g (335) to 0.62 g (DBS-7). The estimates of PCV (27.20%) and GCV (27.03%) were high and heritability estimate was high 98.8 per cent with high GAM of 55.81 per cent in sufficient condition.

4.1.2.9 Leaf area (cm^2)

Genotypes differed significantly for leaf area with average of 35.12 cm^2 and mean ranged from 16.83 cm^2 (335) to 59.73 cm^2 (DBS-7). The estimates of PCV (36.20%) and GCV (35.78%) were high along with high heritability (97.7%) with high GAM of 72.86 per cent under deficient condition.

In sufficient condition average of this trait was 54.36 cm^2 and mean value ranged from 31.75 cm^2 (335) to 79.78 cm^2 (DBS-14). The estimates of PCV (29.35%) and GCV (28.72%) were high. The estimates of heritability was high (95.8%) with high GAM of 57.91 per cent.

4.1.2.10 Root surface area (mm^2)

Wide variation was observed for the root surface area in deficient conditions. Average was 477.83 mm^2 and range was 102.50 mm^2 (7581-7) to 11705 (113 PLU-445) with high GCV (46.16%) and PCV (47.30%). The heritability value was high 95.3% with highest GAM of 92.81% in deficient condition.

Whereas, in sufficient condition average of this trait was 849.3 mm^2 and mean value ranged from 440.0 mm^2 (NE) to 1200 mm^2 (DBS-14). The estimates of PCV (26.87%) and GCV (26.47%) were high and value of heritability was high 97.0 per cent with high GAM of 53.70 per cent.

4.1.2.11 Root to shoot ratio

The average of root to shoot ratio was 0.52 and mean ranged from 0.42 (447.2) to 0.66 (119PLU-283). The estimates of PCV (14.40%) and GCV (13.70%) were moderate. The heritability estimates was high (90.5%) with high GAM of 26.92 per cent in deficient condition.

Whereas, in sufficient condition, average root to shoot ratio was 0.46 and mean ranged from 0.34 (447.2) to 0.68 (335). The coefficient variability parameters were moderate PCV (17.57%) and GCV (17.19%). The heritability estimate was high of 95.7 per cent with high GAM of 34.78 per cent.

4.1.2.12 Total P uptake (mg per plant)

Total P uptake of both root and shoot differed significantly among genotypes in deficient condition with an average of 0.80 mg per plant. The mean ranged from 0.42 mg per plant (NE) and 1.28 mg per plant (DBS-22). The high heritability value was recorded (95.4%) with high GAM of 58.75% and genotypes exhibited high PCV (29.53%) and GCV (28.85%) estimates.

In sufficient condition average was 1.09 mg per plant and genotype mean ranged from 0.58 mg per plant (ER.SEL495) to 1.60 mg per plant (DBS-14). The estimates of PCV (25.53%) and GCV (24.21%) were high. The heritability estimates was 89.9 per cent with high GAM of 47.70 per cent.

4.1.3 Mean, range and variability parameters at the time of harvesting

The mean, range, phenotypic and genotypic coefficients of variability, heritability and genetic advance over mean for the 12 characters studied are presented in Table 5

Table 4: Mean range and variability parameters of root, shoot morphological traits and phosphorus uptake under P deficient and P sufficient conditions at 45 DAS in blackgram

Sl No.	Character	Phosphorus level	Mean	Range	PCV %	GCV %	h %	GA	GAM %
1	Plant height (cm)	50% P	8.52	6.80-11.40	14.64	12.24	69.9	1.80	21.12
		100% P	9.74	8.12-13.90	14.39	13.03	82.0	2.37	24.33
2	Root length (cm)	50% P	17.63	13.90-21.40	11.92	10.25	74.0	3.20	18.15
		100% P	21.21	17.05-26.00	12.85	12.13	89.1	5.00	23.57
3	Lengthiest lateral root length (cm)	50% P	15.32	11.65-17.55	10.32	7.56	53.6	1.75	11.43
		100% P	17.05	13.25-22.65	16.16	14.98	85.9	4.88	28.62
4	Root volume (mm^3)	50% P	2.31	1.35-3.60	34.55	27.69	64.2	1.06	45.88
		100% P	3.59	2.50-4.50	22.83	15.74	47.6	0.80	22.25
5	Root collar diameter (mm)	50% P	0.21	0.14-0.27	16.26	10.18	39.2	0.03	14.28
		100% P	0.23	0.19-0.29	12.40	9.35	56.9	0.03	13.04
6	Number of lateral roots	50% P	6.54	4.00-8.25	19.33	15.35	63.1	1.63	24.92
		100% P	5.31	3.75-6.77	17.83	13.03	53.4	1.04	19.58
7	Root dry weight (g)	50% P	0.18	0.15-0.22	11.37	10.68	88.4	0.04	22.22
		100% P	0.14	0.10-0.22	20.96	19.10	83.1	0.05	35.71
8	Shoot dry weight (g)	50% P	0.36	0.26-0.51	22.52	21.9	95.1	0.16	44.44
		100% P	0.43	0.21-0.62	27.20	27.03	98.8	0.24	55.81
9	Leaf area (cm^2)	50% P	35.12	16.83-59.73	36.20	35.78	97.7	25.59	72.86
		100% P	54.36	31.75-79.48	29.35	28.72	95.8	31.48	57.91
10	Root surface area (mm^2)	50% P	477.83	102.50-1107.5	47.30	46.16	95.3	443.5	92.81
		100% P	849.3	440.0-1200	26.87	26.47	97.0	456.09	53.70
11	Root to shoot ratio	50% P	0.52	0.42-0.66	14.40	13.70	90.5	0.14	26.92
		100% P	0.46	0.34-0.68	17.57	17.19	95.7	0.16	34.78
12	Total P uptake (mg/plant)	50% P	0.80	0.42-1.28	29.53	28.85	95.4	0.47	58.75
		100% P	1.09	0.58-1.60	25.53	24.21	89.9	0.52	47.70

4.1.3.1 Number of pods per plant

In deficient condition average number of pods per plant was 2.87 and genotypic mean ranged from 2.00 (570-152) to 4.25 (NE). The high PCV (23.87%) and moderate GCV (16.99%) were estimated for this trait. The estimates of heritability was 50.7 per cent with high GAM of 25.08 per cent.

In sufficient condition average of number of pods per plant was 3.79 and mean ranged from 2.50 (119PLU-283) to 6.50 (570-152). The estimates of PCV (26.31%) and GCV (21.52%) were high. The estimates of heritability was high 66.9 per cent with high GAM of 36.41 per cent.

4.1.3.2 Pod length

Average pod length was 3.77cm and mean ranged from 3.25cm (7581-7) to 4.55cm (DBS-13). The estimates of PCV (10.21%) and GCV (7.60%) were high. The estimates of heritability was 54.4 per cent with high GAM of 11.67 per cent in deficient P condition.

Whereas, in sufficient condition average pod length was 3.86 cm and mean ranged from 3.10 cm (G-1) to 4.45cm (335). The estimates of PCV (10.64%) was moderate with low GCV (8.63%). The estimates of heritability was high 65.8 per cent with GAM of 14.50 per cent.

4.1.3.3 Number of seeds per pod

In deficient condition average number of seeds per plant was 4.47 and mean ranged from 3.75 (DBS-7) to 5.50 (119PLU283). The estimates of PCV was moderate (13.48%) with low GCV (9.46%). The estimates of heritability was 49.2 per cent with GAM of 13.64 per cent.

Average of number of seeds per plant was 5.12 and mean ranged from 3.75 (BDS-13) to 5.75 (DBS-8). The estimates PCV (11.19%) was moderate with low GCV (8.49%). The estimates of heritability was 57.6 per cent with GAM of 13.28 per cent in sufficient P condition.

4.1.3.4 Shoot dry weight (g)

Average shoot dry weight per plant was 0.33 g and genotypic mean ranged from 0.25 g (DBS-22) to 0.56 (DBS-7). High PCV (27.56%) and GCV (26.69%) were estimated for this trait. The estimates of heritability was high 93.8 per cent with high GAM of 54.54 per cent in deficient P condition.

Whereas, in sufficient condition average shoot dry weight per plant was 0.50 and mean ranged from 0.37 (BDS-14) to 0.67 (447-2). The estimates of PCV (15.85%) and GCV (15.61%) were moderate with high heritability value (97.0%)and high GAM of 32 per cent.

4.1.3.5 Seed yield per plant (g)

In deficient condition average seed yield per plant was 0.42 g and mean ranged from 0.23 (119PLU283) to 0.59 g (DBS-22). The estimates of PCV (20.17%) and GCV (20.02%) were high. The estimates of heritability was high 98.5 per cent with high GAM of 40.47 per cent.

Average seed yield per plant was 0.62 g and mean ranged from 0.42 (797/KC-495) to 1.01 g (NE). The estimates of PCV (20.98%) and GCV (20.47%) were high with high of heritability value (95.0%) and high GAM of 41.93 per cent under sufficient P condition.

4.1.3.6 Seed index

In deficient condition average seed index was 1.10 and mean ranged from 0.90 (7581-7) to 1.47 (DBS-14). Coefficient variability parameters PCV (16.38%) and GCV

(13.46%) were moderate. The estimates of heritability was low 67.6 per cent with high GAM of 22.72 per cent.

In sufficient condition average seed index was 1.11 and mean ranged from 0.68 (570-152) to 1.55 (G-1). The PCV and GCV estimates were moderate with 17.76 and 16.11 per cent respectively with high heritability value (82.3%) and high GAM of 30.63 per cent.

4.1.3.7 Harvest index

Average harvest index was 0.56 and genotypic mean ranged from 0.38 (DBS-7) to 0.70 (DBS-22). The estimates of PCV (14.26%) and GCV (14.64%) were moderate. The estimates of heritability was high 94.9 per cent with GAM of 28.57 per cent in deficient condition.

Whereas, in sufficient condition average harvest index was 0.55 and genotypic mean ranged from 0.45 (447-2) to 0.65 (NE). Low PCV (9.70%) and GCV (9.48%) estimates were noticed with high heritability value (95.5%) and moderate GAM (20.0%) estimates.

4.1.3.8 Shoot P uptake (mg /plant)

Average shoot P uptake mg per plant was 0.29 mg per plant and mean ranged from 0.08 mg per plant (797/KC495) to 0.66 mg per plant (570-152). The estimates of PCV and GCV were high (46.19% and 44.22%, respectively) with high heritability value (91.7%) and high GAM (89.65%) was noticed in deficient condition.

Whereas, in sufficient condition average shoot P uptake mg per plant was 0.63 mg per plant and mean ranged from 0.36mg per plant (797/KC495) to 1.59 (DBS-22). The PCV and GCV estimates were high 49.58 and 48.97 per cent respectively. The estimates of heritability was high 97.5 per cent with high GAM of 101.58 per cent.

4.1.3.9 Seed P uptake per plant

In deficient condition average seed P uptake mg per plant was 1.53 mg per plant and genotypic mean ranged from 1.03 mg per plant (570-152) to 2.66 mg per plant (DBS-25). The estimates of PCV (30.20%) and GCV (29.77%) were high. The estimates of heritability was high 97.2 per cent with high GAM of 60.78 per cent.

Whereas, in sufficient condition average seed P uptake mg per plant was 2.69 mg per plant and mean ranged from 1.13 mg per plant (797/KC495) to 4.67 (570-152). The PCV and GCV estimates were high 27.50 and 27.15 per cent respectively. The estimates of heritability was high 97.5 per cent with high GAM of 55.39 per cent.

4.1.3.10 Total P uptake (mg/plant)

Average total P uptake 1.82 mg per plant and genotypic mean ranged from 1.41 mg per plant (7581-7) to 3.11 mg per plant (DBS-25). The PCV and GCV estimates were high (26.07% and 25.72% respectively) with high heritability value (97.3%) and high GAM of 52.74 per cent in deficient condition.

Whereas, in sufficient condition average total P uptake was 3.33 mg per plant and mean ranged from 1.49 mg per plant (797/KC495) to 5.67 (570-152). The estimates of PCV (28.10%) and GCV (27.78%) were high. The estimates of heritability was high 97.7 per cent with high GAM of 56.75 per cent.

4.2 Association analysis

The phenotypic and genotypic correlation coefficients were determined to know the nature of relationship existing among 18 different genotypes in both deficient P and sufficient P condition at 45 days and at the time of harvesting. The results of genotypic and phenotypic correlation are presented in Table 6,7, 8 and 9

Table 5: Mean range and variability parameters of seed yield, its components and phosphorus uptake under P deficient and P sufficient condition at the of harvesting in blackgram

Sl No.	Character	Phosphorus level	Mean	Range	PCV %	GCV %	h %	GA	GAM %
1	Number of pods/plant	50% P	2.87	2.00-3.75	23.87	16.99	50.7	0.72	25.08
		100% P	3.79	2.50-6.50	26.31	21.52	66.9	1.38	36.41
2	Pod length(cm)	50% P	3.77	3.25-4.55	10.21	7.60	55.4	0.44	11.67
		100% P	3.86	3.10-4.45	10.64	8.63	65.8	0.56	14.50
3	Number of seeds/pod	50% P	4.47	3.75-5.50	13.48	9.46	49.2	0.61	13.64
		100% P	5.12	3.75-5.75	11.19	8.49	57.6	0.68	13.28
4	Shoot dry weight (g)	50% P	0.33	0.25-0.56	27.56	26.69	93.8	0.18	54.54
		100% P	0.50	0.37-0.67	15.85	15.61	97.0	0.16	32.0
5	Seed yield per plant (g)	50% P	0.42	0.23-0.59	20.17	20.02	98.5	0.17	40.47
		100% P	0.62	0.42-1.01	20.98	20.47	95.2	0.26	41.93
6	Seed index (g)	50% P	1.10	0.96-1.47	16.38	13.46	67.6	0.25	22.72
		100% P	1.11	0.68-1.55	17.76	16.11	82.3	0.34	30.63
7	Harvest index	50% P	0.56	0.38-0.70	14.64	14.26	91.7	0.26	28.57
		100% P	0.55	0.45-0.65	9.70	9.48	95.5	0.11	20.0
8	Shoot P uptake (mg/plant)	50% P	0.59	0.08-0.66	64.19	44.22	91.7	0.26	89.65
		100% P	0.63	0.36-1.59	49.58	48.97	97.5	0.64	101.58
9	Seed P uptake (mg/plant)	50% P	1.53	1.03-1.73	30.20	29.77	97.2	0.93	60.78
		100% P	2.69	1.13-3.61	27.50	27.15	97.5	1.49	55.39
10	Total uptake (mg/plant)	50% P	1.82	1.41-3.11	26.07	25.72	97.3	0.96	52.74
		100% P	3.33	1.49-5.67	28.10	27.78	97.7	1.89	56.75

4.2.1 Correlation studies of root and shoot morphological traits towards P uptake under P deficient conditions at 45 DAS

Total P uptake exhibited a positive significant association with root and shoot morphological traits namely, plant height, root volume, root dry weight, shoot dry weight and leaf area. Within the root morphological characters a highly significant positive association was observed between root surface area and root length, root dry weight and root volume at both levels and number of lateral roots exhibited a positive significant association with lengthiest lateral root length at only genotypic level.

Similarly, within the shoot morphological traits, a positive significant association was present between leaf area and plant height, shoot dry weight and plant height at both levels. A significant positive association was present between root and shoot morphological traits namely root dry weight and root volume exhibited significant association with plant height and leaf area exhibited significant association with root volume and root dry weight at both levels. The correlation of root to shoot ratio with plant height, root volume, root dry weight, shoot dry weight and leaf area was highly negative significant at both levels in addition this also exhibited negative significant association with LLRL only at genotypic level.

4.2.2 Correlation studies of root and shoot morphological traits towards P uptake under P sufficient conditions at 45 DAS

Total P uptake exhibited positive significant correlation with root and shoot morphological traits like leaf area at both levels, root volume and root dry weight only at genotypic level and LLRL only at phenotypic level. The correlation of total P uptake with LLRL at genotypic level and with root length at both levels was negative significant. Among root morphological characters, a positive significant association was noticed between root dry weight and root volume, LLRL and root length at both levels. Root surface area exhibited significant association with root volume and further correlation of number of lateral roots with root collar diameter exhibited positive significant association only at genotypic level.

Within shoot morphological characters a significant positive association was observed between leaf area with plant height and shoot dry weight, shoot dry weight with plant height was observed at both levels. Among the root and shoot morphological traits, there was a significant correlation observed between root surface area with shoot dry weight and leaf area, leaf area with root volume and root dry weight, shoot dry weight with root volume and root dry weight, root dry weight with root volume, LLRL with root length. Shoot dry weight, root dry weight and root volume were exhibited negative significant association with root length was noticed at both levels.

The correlation of root surface area with plant height and root volume was positive significant only at genotypic correlation. A root to shoot ratio manifested negative significant association with shoot dry weight at both levels and the correlation of root:shoot ratio with root volume, leaf area and root surface area was negative significant only at genotypic level.

4.2.3 Correlation studies of seed yield and its components towards P uptake under P deficient condition at the time of harvesting

Total P uptake exhibited a positive significant association with seed yield and seed P uptake. There was a significant positive correlation was present between seed P uptake with seed yield and harvest index, harvest index with seed yield. Number of seeds per pod revealed a significant negative association with number of pods per plant, similarly the correlation of harvest index with shoot dry weight was negative significant at both levels under P deficient conditions.

Table 6: Genotypic and phenotypic correlation among root, shoot morphological and phosphorous uptake traits under P deficient condition at 45 DAS in blackgram

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	GC	1.000	0.070	0.090	0.730**	0.458	0.415	0.728**	0.845**	0.817**	0.241	-0.701**	0.864**
	PC	1.000	0.096	0.039	0.577*	0.192	0.329	0.610**	0.673**	0.668**	0.224	-0.519*	0.666**
X_2	GC		1.000	0.223	0.303	-0.343	-0.023	0.201	-0.112	-0.041	0.554*	0.323	-0.080
	PC		1.000	0.385	0.287	-0.076	-0.097	0.247	-0.035	-0.060	0.465*	0.230	-0.055
X_3	GC			1.000	-0.320	-0.445	0.548*	-0.029	-0.321	-0.338	0.318	0.523*	-0.208
	PC			1.000	-0.120	-0.066	0.238	0.087	-0.164	-0.233	0.216	0.345	-0.105
X_4	GC				1.000	-0.098	0.056	0.932**	0.944**	0.872**	0.413	-0.753**	0.742**
	PC				1.000	0.006	-0.019	0.802**	0.761**	0.697**	0.333	-0.558*	0.580*
X_5	GC					1.000	0.455	0.130	0.329	0.153	0.030	-0.411	0.230
	PC					1.000	0.267	0.081	0.281	0.061	-0.016	-0.367	0.153
X_6	GC						1.000	0.341	0.119	0.075	0.217	0.097	0.219
	PC						1.000	0.243	0.097	0.067	0.123	0.050	0.184
X_7	GC							1.000	0.881**	0.783**	0.249	-0.616**	0.619**
	PC							1.000	0.845**	0.748**	0.261	-0.525*	0.591**
X_8	GC								1.000	0.885**	0.158	-0.907**	0.744**
	PC								1.000	0.860**	0.153	-0.888**	0.738**
X_9	GC									1.000	0.222	-0.778**	0.817**
	PC									1.000	0.224	-0.728**	0.807**
X_{10}	GC										1.000	-0.029	0.435
	PC										1.000	-0.004	0.407
X_{11}	GC											1.000	-0.672**
	PC											1.000	-0.649**
X_{12}	GC												1.000
	PC												1.000

* - Significant at 5% level of probability ** - Significant at 1% level of probability GC – Genotypic correlation PC – Phenotypic correlation

X_1 – Plant height (cm) X_2 – Root length (cm) X_3 – Lengthiest lateral root length (cm) X_4 – Root volume (mm^3)
X_5 – Root collar diameter(mm) X_6 – Number of lateral roots X_7 – Root dry weight (g) X_8 – Shoot dry weight (g)
X_9 – Leaf area (cm^2) X_{10} – Root surface area (mm^2) X_{11} – Root to shoot ratio X_{12} – Total P uptake (mg/plant)

Table 7: Genotypic and phenotypic correlation among root, shoot morphological and phosphorus uptake traits under P sufficient condition at 45 DAS of blackgram

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	GC	1.000	-0.191	0.258	0.392	0.243	0.113	0.419	0.660**	0.705**	0.511*	-0.511	0.394
	PC	1.000	-0.149	0.226	0.384	0.236	0.179	0.364	0.594**	0.641**	0.464	-0.441	0.313
X_2	GC		1.000	0.649**	-0.781**	0.064	-0.040	-0.659**	-0.584*	-0.436	-0.178	0.456	-0.601**
	PC		1.000	0.507*	-0.531*	0.078	0.006	-0.538*	-0.545*	-0.384	-0.176	0.431	-0.518*
X_3	GC			1.000	-0.086	0.398	0.153	-0.260	0.006	-0.199	0.271	-0.110	-0.638**
	PC			1.000	-0.053	0.264	0.078	-0.248	-0.003	-0.200	0.252	-0.105	0.553*
X_4	GC				1.000	0.350	-0.052	0.641**	0.745**	0.648**	0.524*	-0.656**	0.525*
	PC				1.000	0.224	0.197	0.555*	0.546*	0.505*	0.365	-0.382	0.340
X_5	GC					1.000	0.526*	0.015	0.063	0.296	0.181	-0.055	0.254
	PC					1.000	0.308	-0.080	0.025	0.199	0.131	-0.059	0.065
X_6	GC						1.000	-0.102	-0.031	0.060	0.042	-0.119	0.261
	PC						1.000	-0.004	-0.007	0.065	0.034	-0.063	0.215
X_7	GC							1.000	0.782**	0.492*	0.150	-0.458	0.486*
	PC							1.000	0.736*	0.501*	0.119	-0.336	0.465
X_8	GC								1.000	0.609**	0.492*	-0.888**	0.400
	PC								1.000	0.605**	0.481*	-0.861**	0.465
X_9	GC									1.000	0.559*	-0.479*	0.566**
	PC									1.000	0.544*	-0.436	0.532*
X_{10}	GC										1.000	-0.471*	0.072
	PC										1.000	-0.463	0.060
X_{11}	GC											1.000	-0.282
	PC											1.000	-0.244
X_{12}	GC												1.000
	PC												1.000

* - Significant at 5% level of probability ** - Significant at 1% level of probability GC – Genotypic correlation PC– Phenotypic correlation

X_1 – Plant height (cm) X_2 – Root length (cm) X_3 – Lengthiest lateral root length (cm) X_4 – Root volume (mm^3)
X_5 – Root collar diameter(mm) X_6 – Number of lateral roots X_7 – Root dry weight (g) X_8 – Shoot dry weight (g)
X_9 – Leaf area (cm^2) X_{10} – Root surface area (mm^2) X_{11} – Root to shoot ratio X_{12} – Total P uptake (mg/plant)

4.2.4 Correlation studies of seed yield and its components towards P uptake under P sufficient condition at the time of harvesting

A significant positive association of total P uptake was observed with number of pods per plant, shoot P uptake and seed P uptake. Seed P uptake was also significantly correlated with number of pods per plant, seed yield and shoot P uptake. Highly significant positive association of harvest index with seed yield was noticed, but correlation of this trait with shoot dry weight was negative significant at both levels.

Only at genotypic level, seed yield and shoot dry weight exhibited a significant positive association with number of pods per plant and a negative association of number of seeds per plant with number of pods per plant. A significant negative association was present between seed index with number of pods per plant and pod length.

4.3 Path coefficient analysis

4.3.1 Path coefficient analysis of root and shoot morphological traits at 45 DAS

4.3.1.1 Plant height

Plant height had low negative direct effect (-0.188) at genotypic path and low positive direct effect (0.134) in phenotypic path on total P uptake. However, it exhibited positive indirect effect (1.632) via shoot dry weight followed by leaf area (0.548), root volume, number of lateral roots and its indirect effect was negative through root dry weight (-1.236) at genotypic path. Where as at phenotypic level a positive indirect effect via leaf area(0.359) followed by shoot dry weight (0.352), root surface area and negative indirect effect was noticed by root dry weight(-0.245) in deficient P condition.

In sufficient plant height had low negative direct effect (-1.750) at genotypic and low positive direct effect (0.399) at phenotypic level on total P uptake. Indirect effect of this trait was high and positive through shoot dry weight (4.722) followed by leaf area (1.392), root length and it had high negative direct effect via root to shoot ratio (-2.227) at genotypic path. Low positive indirect effect was observed by root to shoot ratio(0.388) and it exhibited low negative indirect effect by shoot dry weight (-0.779).

4.3.1.2 Root length

Root length had low positive direct effect (0.127) at genotypic path and low negative (-0.098) at phenotypic path. Root length exhibited low positive indirect effect via root to shoot ratio (0.185) and its indirect effect was negative by root dry weight (-0.341) at genotypic path. Where as at phenotypic path, indirect effect of this trait was positive through root surface area (0.132) and a low negative indirect effect was noticed through root dry weight (0.099) at deficient P condition.

Where as at sufficient P condition, root length had high negative direct effect (-2.014) at genotypic level and low negative direct effect (-0.091) at phenotypic path. It revealed that high positive indirect effect via root dry weight (2.235) and a high negative indirect effect (-4.184) was observed trough shoot dry weight at genotypic path. Indirect effect of this trait was low positive through shoot dry weight (0.715) and its indirect effect (-0.428) via root dry weight which was negative at phenotypic path.

4.3.1.3 Lengthest lateral root length (LLRL)

In deficient condition, LLRL had low positive direct effect (0.104 and 0.067) on total P uptake at genotypic and phenotypic path respectively. However, its indirect effect was positive through number of lateral roots (0.254) followed by leaf area (0.227) at genotypic path. A positive indirect effect by root surface area (0.063) and negative indirect effect via shoot dry weight (-0.086) by this trait at phenotypic level was observed.

Table 8: Genotypic and phenotypic correlation of seed yield, its components and phosphorus uptake trait under P deficient condition at time of harvesting in blackgram

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	GC	1.000	0.326	-0.821**	0.123	-0.104	-0.380	-0.192	-0.373	0.007	-0.096
	PC	1.000	0.150	-0.497*	0.019	-0.051	-0.199	-0.059	-0.263	-0.001	-0.076
X_2	GC		1.000	-0.036	-0.010	-0.063	0.194	-0.076	0.037	0.262	0.264
	PC		1.000	0.132	0.017	-0.065	-0.013	-0.088	0.062	0.228	0.239
X_3	GC			1.000	-0.179	-0.124	0.353	-0.001	0.400	-0.037	0.075
	PC			1.000	-0.085	-0.075	0.117	-0.021	0.237	-0.002	0.065
X_4	GC				1.000	-0.107	0.175	-0.755**	0.653**	-0.236	-0.050
	PC				1.000	0.100	0.121	-0.765**	0.651**	-0.239	-0.048
X_5	GC					1.000	0.389	0.717**	-0.250	0.566*	0.481*
	PC					1.000	0.331	0.701**	-0.241	0.555*	0.471*
X_6	GC						1.000	0.091	0.098	0.009	0.036
	PC						1.000	0.098	0.033	0.005	0.015
X_7	GC							1.000	-0.618**	0.517*	0.333
	PC							1.000	-0.617*	0.511*	0.322
X_8	GC								1.000	-0.039	0.238
	PC								1.000	-0.048	0.237
X_9	GC									1.000	0.961**
	PC									1.000	0.959*
X_{10}	GC										1.000
	PC										1.000

* - Significant at 5% level of probability ** - Significant at 1% level of probability
GC – Genotypic correlation PC – Phenotypic correlation

X_1 – Number of pods per plant X_2 – Pod length (cm) X_3 – Number of seeds per pod X_4 – Soot dry weight (g)
X_5 – Seed yield (g) X_6 – Seed index (g) X_7 – Harvest index X_8 – Shoot P uptake (mg/plant)
X_9 – Seed P uptake (mg/plant) X_{10} – Total P uptake (mg/plant)

Table 9: Genotypic and phenotypic correlation of seed yield, its components and phosphorus uptake trait under P sufficient condition at time of harvesting in blackgram

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	GC	1.000	0.160	-0.477*	0.447*	0.470*	-0.459*	0.117	0.251	0.625**	0.578*
	PC	1.000	0.006	-0.445	0.366	0.440	-0.335	0.142	0.191	0.540*	0.492*
X_2	GC		1.000	0.119	-0.148	0.004	-0.560*	0.151	-0.086	0.161	0.098
	PC		1.000	0.282	-0.135	-0.005	-0.436	0.130	-0.048	0.142	0.096
X_3	GC			1.000	-0.457	0.040	0.340	0.381	-0.445	-0.075	-0.209
	PC			1.000	-0.380	0.019	0.163	0.299	-0.309	0.046	-0.141
X_4	GC				1.000	0.213	-0.070	-0.527*	0.313	0.341	0.375
	PC				1.000	0.209	-0.069	-0.525*	0.310	0.331	0.367
X_5	GC					1.000	0.250	0.705**	-0.150	0.468*	0.319
	PC					1.000	0.264	0.709**	-0.133	0.483*	0.337
X_6	GC						1.000	0.285	-0.030	-0.047	-0.047
	PC						1.000	0.295	-0.015	-0.013	-0.015
X_7	GC							1.000	-0.329	0.224	0.066
	PC							1.000	-0.311	0.244	0.088
X_8	GC								1.000	0.490*	0.725**
	PC								1.000	0.486*	0.723**
X_9	GC									1.000	0.956**
	PC									1.000	0.955**
X_{10}	GC										1.000
	PC										1.000

* - Significant at 5% level of probability ** - Significant at 1% level of probability
GC – Genotypic correlation PC – Phenotypic correlation

X_1 – Number of pods per plant X_2 – Pod length (cm) X_3 – Number of seeds per pod X_4 – Soot dry weight (g)
X_5 – Seed yield (g) (mg/plant) X_6 – Seed index (g) X_7 – Harvest index X_8 – Shoot P uptake
X_9 – Seed P uptake (mg/plant) X_{10} – Total P uptake (mg/plant)

LLRL exhibited positive direct effect (1.242) at genotypic path and low negative direct effect (-0.531) at phenotypic path. Indirect effect of this trait was positive through root dry weight (0.881) and a negative indirect effect (-1.307) via root length at genotypic path. Where as in phenotypic path positive indirect effect was noticed by root to shoot ratio (0.092) and it had low negative indirect effect (-0.197) by root dry weight in sufficient condition.

4.3.1.4 Root volume

Root volume had a positive direct effect (0.409 and 0.036) at genotypic and phenotypic level on total P uptake. Low to medium positive indirect effect was noticed through shoot dry weight (1.823 and 0.399) and also it had low to medium negative indirect effect through root dry weight (-1.581 and -0.322) at both genotypic and phenotypic path in deficient condition.

Where as under sufficient P condition root volume exhibited negative direct effect (-1.159 and- 0.082) at genotypic and phenotypic path respectively. However, it had high positive indirect effect via shoot dry weight (5.334) and it showed high and negative indirect effect (-2.173) via root dry weight in genotypic path. A positive indirect effect was observed through root dry weight (0.441) and it had negative indirect effect via shoot dry weight (-0.717) at phenotypic path.

4.3.1.5 Root collar diameter

Root collar diameter exhibited negative direct effect (-0.050 and -0.015) on total P uptake at genotypic and phenotypic path, respectively. Its Indirect effect was positive through shoot dry weight (0.636 and 0.147) and also negative effect was observed through root to shoot ratio (-0.236 and -0.028) at genotypic and phenotypic path respectively under in deficient condition.

This trait revealed a negative (-0.63) and positive (0.120) indirect effect on total P uptake at genotypic and phenotypic path respectively. At genotypic path root collar diameter exhibited a low positive indirect effect via leaf area (0.584) and it had negative indirect effect (-0.425) via plant height. Whereas in phenotypic path, low and positive indirect effect of this trait through plant height (0.094) and a negative indirect effect (0.140) via LLRL in sufficient condition.

4.3.1.6 Number of lateral roots

Number of lateral roots exhibited positive direct effect (0.464 and 0.090) on total P uptake mg per plant at genotypic and phenotypic path, respectively. Low positive indirect effect via shoot dry weight (0.231 and 0.051) and also negative indirect effect via root dry weight (-0.578 and -0.097) at both paths under deficient condition.

On contrary, in sufficient P condition number of lateral roots had low positive indirect effect (0.486 and 0.094) at genotypic and phenotypic path respectively. Low positive indirect effect of this trait via root dry weight (0.346) and a negative indirect effect via root to shoot ratio (-0.517) was noticed at genotypic path. A positive indirect effect was noticed by plant height (0.071) and negative indirect effect via LLRL (-0.041) trait at phenotypic path.

4.3.1.7 Root dry weight

In deficient condition root dry weight exhibited low negative direct effect (-1.696 and -0.402) on total P uptake at genotypic and phenotypic path respectively. However, it had positive indirect effect via shoot dry weight (1.702) and a negative indirect effect via root to shoot ratio (-0.353) at genotypic path. Low and positive indirect effect was noticed through shoot dry weight (0.442) and it had low negative indirect effect via root to shoot ratio (-0.040) at phenotypic level.

Root dry weight had high negative direct effect (-3.390) at genotypic path and positive direct effect (0.795) at phenotypic path. However, its indirect effect was high and positive through shoot dry weight (5.600) and negative through plant height (-0.198) at genotypic path.

Table 10: Genotypic and phenotypic path analysis among root, hoot morphological and phosphorus uptake traits under P deficient condition at 45 DAS in blackgram

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	rg rp
X_1	GP	-0.188	0.009	0.009	0.299	-0.023	0.192	-1.236	1.632	0.548	0.023	-0.402	0.863**
	PP	0.134	-0.009	0.003	0.021	-0.003	0.030	-0.245	0.352	0.359	0.065	-0.040	0.667**
X_2	GP	-0.015	0.127	0.023	0.124	0.017	-0.011	-0.341	-0.217	-0.028	0.052	0.0185	-0.084
	PP	0.013	-0.098	0.026	0.010	0.001	-0.009	-0.099	-0.019	-0.032	0.135	0.018	-0.054
X_3	GP	-0.017	0.028	0.104	-0.131	0.022	0.254	0.049	-0.621	0.227	0.030	0.299	0.244
	PP	0.005	-0.038	0.067	-0.004	0.001	0.021	-0.035	-0.086	-0.125	0.063	0.026	-0.105
X_4	GP	-0.138	0.039	-0.033	0.409	0.005	0.026	-1.581	1.823	0.585	0.039	-0.432	0.742*
	PP	0.078	-0.028	-0.008	0.036	0.000	-0.002	-0.322	0.399	0.375	0.096	-0.043	0.581*
X_5	GP	-0.086	-0.044	-0.046	-0.040	-0.050	0.211	-0.221	0.636	0.102	0.003	-0.236	0.229
	PP	0.026	0.007	-0.004	0.000	-0.015	0.024	-0.033	0.147	0.033	-0.005	-0.028	0.152
X_6	GP	-0.078	-0.003	0.057	0.023	-0.023	0.464	-0.578	0.231	0.051	0.021	0.056	0.220
	PP	0.044	0.009	0.016	-0.001	-0.004	0.090	-0.097	0.051	0.036	0.036	0.004	0.184
X_7	GP	-0.137	0.025	-0.003	0.381	-0.006	0.158	-1.696	1.702	0.525	0.024	-0.353	0.620**
	PP	0.082	-0.024	0.006	0.029	-0.001	0.022	-0.402	0.442	0.402	0.075	-0.040	0.591*
X_8	GP	-0.159	-0.014	-0.033	0.386	-0.016	0.055	-1.494	1.931	0.593	0.015	-0.519	0.745**
	PP	0.090	0.003	-0.011	0.027	-0.004	0.009	-0.339	0.524	0.462	0.044	-0.068	0.737**
X_9	GP	-0.154	-0.005	-0.035	0.357	-0.008	0.035	-1.328	1.709	0.671	0.021	-0.446	0.817**
	PP	0.090	0.006	-0.016	0.025	-0.001	0.006	-0.300	0.450	0.537	0.065	-0.056	0.807**
X_{10}	GP	-0.045	0.070	0.033	0.169	-0.001	0.101	-0.423	0.306	0.149	0.095	-0.017	0.437
	PP	0.030	-0.046	0.014	0.012	0.000	0.011	-0.105	0.080	0.120	0.290	0.000	0.406
X_{11}	GP	0.132	0.041	0.054	-0.308	0.020	0.045	1.045	-1.751	-0.522	-0.003	0.573	-0.674**
	PP	-0.070	-0.023	0.023	-0.020	0.005	0.004	0.211	-0.465	-0.391	-0.001	0.076	-0.651**

rg: Genotypic correlation with total P uptake
rp: Phenotypic correlation with total P uptake
GP – Genotypic path
PP – Phenotypic path
Residue/G -0.2093
Residue/P -0.2265
Bold figure indicates direct effects

X_1 – Plant height (cm) X_2 – Root length (cm) X_3 – Lengthiest lateral root length (cm) X_4 – Root volume (mm^3)
X_5 – Root collar diameter(mm) X_6 – Number of lateral roots X_7 – Root dry weight (g) X_8 – Shoot dry weight (g)
X_9 – Leaf area (cm^2) X_{10} – Root surface area (mm^2) X_{11} – Root to shoot ratio X_{12} – Total P uptake (mg/plant

Whereas at phenotypic path it had a positive indirect effect through root to shoot ratio (0.296) and low negative indirect effect through shoot dry weight (-0.965) in sufficient condition.

4.3.1.8 Shoot dry weight

In deficient condition, shoot dry weight had a low positive direct effect (1.931, 0.524) on total P uptake at genotypic and phenotypic path respectively. A positive indirect effect via leaf area (0.593) was exhibited by this trait and negative indirect effect via root dry weight (-1.494) at genotypic path. It exhibited low positive indirect effect via leaf area (0.462) and negative indirect effect via root dry weight (-0.339) at phenotypic path.

In sufficient condition it had high and positive direct effect (7.159) at genotypic path and it had low negative indirect effect (-1.312) at phenotypic path. However, it had positive indirect effect via leaf area (1.202) and also it had high and negative indirect effect via root to shoot ratio (-3.868) at genotypic path. The positive indirect effect was observed through root to shoot ratio (0.758) and negative indirect effect via root volume (-0.045) at phenotypic path.

4.3.1.9 Leaf area

Leaf area exhibited a positive direct effect (0.671 and 0.537) on total P uptake at genotypic and phenotypic path respectively. Low positive indirect effect was noticed of this trait through shoot dry weight (1.709) and its indirect effect was negative via root dry weight (-1.328) at genotypic path. Whereas at phenotypic path, it had low positive indirect effect via shoot dry weight (0.450) and it had low and negative indirect effect by root dry weight (-0.300) in deficient condition.

On contrary, in P sufficient condition leaf area had a positive direct effect (1.974 and 0.122) at genotypic and phenotypic path respectively. It exhibited high positive indirect effect via shoot dry weight (4.360) and it had negative indirect effect by root to shoot ratio (-2.087) at genotypic path. Whereas, at phenotypic path, it had positive indirect effect through root dry weight (0.398) followed by root to shoot ratio (0.384) and a negative indirect effect by root volume (0.041).

4.3.1.10 Root surface area

The deficient condition root surface area had low and positive direct effect (0.050 and 0.290) on total P uptake per plant at genotypic and phenotypic path respectively. It had low positive indirect effect via shoot dry weight (0.306) and was low negative indirect effect via root dry weight (-0.423). Whereas, at phenotypic path and at phenotypic path it exhibited low positive indirect effect via leaf area (0.120) which was negative indirect effect and it had low and negative indirect effect via root dry weight (-0.105).

Root surface area had a negative direct effect (-1.199) at genotypic and low positive direct effect (0.065) at phenotypic path on total P uptake. It had high positive indirect effect via shoot dry weight (3.524) and it had high negative indirect effect via root to shoot ratio (-2.050) at genotypic path. Whereas at phenotypic path ad it had positive indirect effect via root to shoot ratio (0.408) and low negative indirect effect via shoot dry weight (-0.631) sufficient P condition.

4.3.1.11 Root to shoot ratio

Root to shoot ratio had low positive effect (0.573 and 0.076) at genotypic and phenotypic path, respectively. A positive indirect effect of this trait was observed through root dry weight (1.045) followed by plant height (0.132) and low negative indirect effect via shoot dry weight (-1.751) in genotypic path. Similarly at phenotypic path it exhibited a positive indirect effect via root dry weight (0.211) and it had low negative indirect effect via shoot dry weight (-0.465) in deficient condition.

This trait had high positive direct effect (4.357) in genotypic and negative direct effect (-0.881) at phenotypic path. It had positive indirect effect through root dry weight (1.552) and high and negative indirect effect via shoot dry weight (-6.355) at genotypic path. At phenotypic

Table 11: Genotypic and phenotypic path analysis among root, shoot morphological traits and phosphorus uptake traits under P sufficient condition at 45 DAS in blackgram

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	rg rp
X_1	GP	-1.750	0.385	0.320	-0.454	-0.015	0.055	-1.421	4.722	1.392	-0.613	-2.227	0.394
	PP	0.399	0.014	-0.120	-0.120	0.028	0.017	0.289	-0.779	0.078	0.030	0.388	0.301
X_2	GP	0.335	-2.014	0.806	0.905	-0.004	-0.020	2.235	-4.184	-0.861	0.213	1.989	-0.600**
	PP	-0.059	-0.091	-0.270	0.043	0.009	0.001	-0.428	0.715	-0.047	-0.012	0.380	-0.519*
X_3	GP	-0.451	-1.307	1.242	0.100	-0.025	0.074	0.881	0.045	-0.394	-0.325	-0.478	-0.638**
	PP	0.090	-0.046	-0.531	0.004	0.032	0.007	-0.197	0.004	-0.024	0.016	0.092	0.553*
X_4	GP	-0.686	1.572	-0.107	-1.159	0.022	-0.025	-2.173	5.334	1.279	-0.629	-2.859	0.569*
	PP	0.153	0.048	0.028	-0.082	0.027	0.019	0.441	-0.717	0.061	0.024	0.337	0.339
X_5	GP	-0.425	-0.129	0.494	-0.405	-0.063	0.255	-0.049	0.451	0.584	-0.217	-0.241	0.255
	PP	0.094	-0.007	-0.140	-0.018	0.120	0.029	-0.064	-0.033	0.024	0.009	0.052	0.066
X_6	GP	-0.198	0.081	0.190	0.060	-0.033	0.486	0.346	-0.223	0.119	-0.051	-0.517	0.260
	PP	0.071	-0.001	-0.041	-0.016	0.037	0.094	-0.003	0.009	0.008	0.002	0.055	0.215
X_7	GP	-0.734	1.328	-0.323	-0.743	-0.001	-0.050	-3.390	5.600	0.972	-0.179	-1.995	0.486*
	PP	0.145	0.049	0.132	-0.045	-0.010	0.000	0.795	-0.965	0.061	0.008	0.296	0.466
X_8	GP	-1.155	1.177	0.008	-0.864	-0.004	-0.015	-2.651	7.159	1.202	-0.590	-3.868	0.399
	PP	0.237	0.050	0.002	-0.045	0.003	-0.001	0.585	-1.312	0.074	0.031	0.758	0.382
X_9	GP	-1.234	0.878	-0.247	-0.750	-0.019	0.029	-1.668	4.360	1.974	-0.670	-2.087	0.566*
	PP	0.256	0.035	0.106	-0.041	0.024	0.006	0.398	-0.794	0.122	0.036	0.384	0.532*
X_{10}	GP	-0.895	0.358	0.337	-0.608	-0.011	0.021	-0.507	3.524	1.103	-1.199	-2.050	0.073
	PP	0.185	0.016	-0.134	-0.030	0.016	0.003	0.094	-0.631	0.066	0.065	0.408	0.058
X_{11}	GP	0.895	-0.919	-0.136	0.760	0.003	-0.058	1.552	-6.355	-0.946	0.564	4.357	-0.283
	PP	-0.176	-0.039	0.056	0.031	-0.007	-0.006	-0.267	1.129	-0.053	-0.030	-0.881	-0.243

rg: Genotypic correlation with total P uptake
rp: Phenotypic correlation with total P uptake
GP – Genotypic path
PP – Phenotypic path
Residue/G 0.7481
Residue/P 0.2823
Bold figure indicates direct effects

X_1 – Plant height (cm) X_2 – Root length (cm) X_3 – Lengthiest lateral root length (cm) X_4 – Root volume (mm^3)
X_5 – Root collar diameter(mm) X_6 – Number of lateral roots X_7 – Root dry weight (g) X_8 – Shoot dry weight (g)
X_9 – Leaf area (cm^2) X_{10} – Root surface area (mm^2) X_{11} – Root to shoot ratio X_{12} – Total P uptake (mg/plant)

path, it had low positive indirect effect via shoot dry weight (1.129) and low negative indirect effect by root dry weight (-0.267) in sufficient condition.

4.3.2 Path coefficient analysis of seed yield and its components towards P uptake at the time of harvest

4.3.2.1 Number of pods per plant

It deficient condition number of pods per plant had low negative direct effect (-0.003) on total P uptake only at genotypic path. However, it had low positive indirect effect through seed P uptake (0.007) and low negative indirect effect via shoot P uptake (-0.102) at genotypic path. The number of pods per plant exhibited only indirect effect via shoot P uptake (-0.075) at phenotypic path.

In sufficient condition it had very negligible positive direct effect (0.001) on total P uptake only in genotypic path. A positive indirect effect was noticed of this trait through seed P uptake (0.493 and 0.427) at both genotypic and phenotypic path respectively. Only negative indirect effect was observed by root volume (-0.001) only at genotypic path.

4.3.2.2 Pod length

In deficient condition, pod length had negligible positive direct effect (0.001) on total P only at genotypic level. Indirect effect of pod length was positive via seed P uptake (0.254 and 0.222) at genotypic and phenotypic levels respectively. Only low negative indirect effect was noticed by number of pods (-0.001) in genotypic path only.

In sufficient condition, pod length had very less positive direct effect (0.001) at genotypic path. However, it had positive indirect effect (0.127 and 0.112) and negative indirect effect (-0.029 and -0.016) via seed P uptake at genotypic and phenotypic path respectively.

4.3.2.3 Number of seeds per pod

In deficient condition number of seeds per pod had very low and negative direct effect (-0.001) only at genotypic path. A negative indirect effect of number of seeds per pod was negative through seed P uptake (-0.036 and -0.002) and positive indirect effect by shoot P uptake (0.109 and 0.067) at genotypic and phenotypic path respectively.

Number of seeds per pod exhibited zero direct effect in both path and it had only negative indirect effect via shoot P uptake (-0.150 and -0.105) at genotypic and phenotypic paths respectively under sufficient condition.

4.3.2.4 Shoot dry weight

In deficient condition, shoot dry weight had negative direct effect (-0.004) on total P uptake only at genotypic path. A positive indirect effect of this trait was observed through shoot P uptake (0.179 and 0.185) and its indirect effect was negative via seed P uptake (-0.230 and -0.233) at genotypic and phenotypic path respectively.

Only in genotypic path, shoot dry weight exhibited positive indirect effect (-0.001) and also it had only positive indirect effect through seed P uptake (0.269 and 0.262) followed by shoot P uptake (0.106 and 0.105) at genotypic and phenotypic path respectively.

4.3.2.5 Seed yield

Seed yield exhibited low positive direct effect (0.005) on total P uptake only in genotypic path. A low positive indirect effect of seed yield through seed P uptake (0.550 and 0.540) and its indirect effect was negative by shoot P uptake (-0.068 and -0.069) at both genotypic and phenotypic path respectively under deficient condition.

Table 12: Genotypic and phenotypic path analysis of seed yield, it components and phosphorus uptake traits under P deficient condition at time of harvesting of blackgram

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	rg rp
X_1	GP	-0.003	0.000	0.001	-0.001	-0.001	0.000	0.002	-0.102	0.007	0.097
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.075	-0.001	0.076
X_2	GP	-0.001	0.001	0.000	0.000	0.000	0.000	0.001	0.010	0.254	0.265
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.222	0.240
X_3	GP	0.003	0.000	-0.001	0.001	0.001	0.000	0.000	0.109	-0.036	0.075
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.067	-0.002	0.065
X_4	GP	0.000	0.000	0.000	-0.004	-0.001	0.000	0.006	0.179	-0.230	0.050
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.185	-0.233	0.048
X_5	GP	0.000	0.000	0.000	0.000	0.005	0.000	-0.006	-0.068	0.550	0.483*
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.069	0.540	0.471*
X_6	GP	0.001	0.000	0.000	-0.001	0.002	-0.001	-0.001	0.027	0.009	0.036
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.005	0.015
X_7	GP	0.001	0.000	0.000	0.003	0.004	0.000	-0.009	-0.169	0.503	0.333
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.175	0.497	0.322
X_8	GP	0.001	0.000	0.000	-0.003	-0.001	0.000	0.005	0.274	-0.038	0.238
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.284	-0.047	0.237
X_9	GP	0.000	0.000	0.000	0.000	0.003	0.000	0.004	-0.011	0.972	0.969**
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.014	0.973	0.959**

rg: Genotypic correlation with total P uptake
rp: Phenotypic correlation with total P uptake
Bold figure indicates direct effects

GP – Genotypic path
PP – Phenotypic path

Residue/G 0.0000
Residue/P 0.0000

X_1 – Number of pods per plant
X_2 – Pod length (cm)
X_3 – Number of seeds per pod
X_4 – Shoot dry weight (g)
X_5 – Seed yield (g)
X_6 – Seed index (g)
X_7 – Harvest index
X_8 – Shoot P uptake (mg/plant)
X_9 – Seed P uptake (mg/plant)
X_{10} – Total P uptake (mg/plant)

Whereas, in sufficient condition seed yield had low positive direct effect (0.001) only at genotypic path. However, it had positive indirect effect via seed P uptake (0.370 and 0.382) and also negative indirect effect was noticed seed yield by shoot P uptake (-0.051 and -0.45) at both genotypic and phenotypic path respectively.

4.3.2.6 Seed index

In deficient condition, seed index had negligible negative (-0.001) direct effect on total P uptake only at genotypic path. Indirect effect of seed index was positive through shoot P uptake (0.027 and 0.009) at both phenotypic and phenotypic path respectively.

On contrary, in sufficient condition, seed index exhibited low positive direct effect (0.001) on total P uptake at genotypic path. However, it had low and positive indirect effect via shoot P uptake (-0.010 and -0.005) at both phenotypic and genotypic path respectively.

4.3.2.7 Harvest index

In deficient condition, harvest index had low negative direct effect (-0.009) on total P uptake only at genotypic path. Indirect effect of harvest index was positive through seed P uptake (0.503 and 0.497) and also negative in direct effect via shoot P uptake (-0.169 and -0.047) at both genotypic and phenotypic levels respectively.

In sufficient condition, harvest index had low negative indirect effect (-0.002) at genotypic path. It had low and positive indirect effect via seed P uptake (0.177 and 0.193) and negative indirect effect via shoot P uptake (-0.111 and -0.105) at both genotypic and phenotypic paths, respectively.

4.3.2.8 Shoot P uptake

Shoot P uptake exhibited a positive direct effect (0.274 and 0.284) on total P uptake at both genotypic and phenotypic path respectively. A positive indirect effect was observed through harvest index (0.005) and a negative indirect effect was noticed by seed P uptake (-0.038 and -0.047)at both genotypic and phenotypic path respectively in deficient condition.

In sufficient condition shoot P uptake exhibited a positive direct effect (0.338 and 0.338) on total P uptake at genotypic and phenotypic path respectively and it had positive indirect effect via seed P uptake (0.387 and 0.384) at both genotypic and phenotypic path respectively.

4.3.2.9 Seed P uptake

In deficient condition, seed P uptake had positive direct effect (0.972 and 0.973) on total P uptake at both genotypic and phenotypic path respectively. A positive indirect effect was observed through harvest index (0.004) and negative indirect effect was observed by this trait through shoot P uptake (-0.011). Whereas in sufficient condition, it had positive indirect effect (0.790 and 0.791) and its indirect effect was positive via shoot P uptake (0.166 and 0.164) at both genotypic and phenotypic path, respectively

4.4 Biochemical studies

Of the several mechanisms, plants adapt to acquire needed P under P deficient conditions exudation of organic acids into rhizosphere and increased activity of these organic acids help the plant to acquire more phosphorus.

Changes in uptake pattern of rape, induced by P starvation, was recorded by Grinsted *et al.* (1982) when rape plants were grown at high root densities in absence of P, soil pH declined from 6.5 to 4.1 within 2 weeks. A relationship between acid phosphatase activity, a constituent of high molecular weight (HMW) root exudates and P stress was also reported by Sachay *et al.* (1991).

Table 13: Genotypic and phenotypic path analysis of seed yield, its components and phosphorus uptake traits under P sufficient condition at time of harvesting in blackgram

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	rg rp
X_1	GP	0.001	0.000	0.000	-0.001	0.001	0.000	0.000	0.085	0.493	0.579*
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.065	0.427	0.492*
X_2	GP	0.000	0.001	0.000	0.000	0.000	0.000	0.000	-0.029	0.127	0.099
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.016	0.112	0.096
X_3	GP	0.000	0.000	0.000	0.001	0.000	0.000	-0.001	-0.150	-0.059	0.209
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.105	-0.037	-0.142
X_4	GP	0.000	0.000	0.000	-0.001	0.000	0.000	0.00 1	0.106	0.269	0.375
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.105	0.262	0.367
X_5	GP	0.000	0.000	0.000	0.000	0.001	0.000	-0.001	-0.051	0.370	0.318
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.045	0.382	0.337
X_6	GP	0.000	0.000	0.000	0.000	0.001	0.001	0.000	-0.010	-0.037	0.047
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.005	-0.010	-0.015
X_7	GP	0.000	0.000	0.000	0.001	0.000	0.000	-0.002	-0.111	0.177	0.066
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.105	0.193	0.088
X_8	GP	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.338	0.387	0.726**
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.338	0.384	0.722*
X_9	GP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.166	0.790	0.956**
	PP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.164	0.791	0.955**

rg: Genotypic correlation with total P uptake
rp: Phenotypic correlation with total P uptake
GP – Genotypic path
PP – Phenotypic path
Residue/G 0.0000
Residue/P 0.0000
Bold figure indicates direct effects

X_1 – Number of pods per plant X_2 – Pod length (cm) X_3 – Number of seeds per pod X_4 – Shoot dry weight (g)
X_5 – Seed yield (g) X_6 – Seed index (g) X_7 – Harvest index X_8 – Shoot P uptake (mg/plant)
X_9 – Seed P uptake (mg/plant) X_{10} – Total P uptake (mg/plant)

Table 20: RF values of organic acids under deficient P and sufficient P conditions in blackgram

SL No.	Genotype	RF Values			
		Deficient P condition		Sufficient P condition	
		Oxalic acid	Citric acid	Oxalic acid	Citric acid
1	DBS-7	-	-	0.23	-
2	DBS-8	-	0.30	0.16	-
3	DBS-13	-	0.31	-	-
4	DBS-14	0.21	0.35	-	0.35
5	DBS-21	-	-	-	-
6	DBS-22	-	0.38	-	-
7	DBS-24	-	0.34	-	0.34
8	DBS-25	0.13	0.32	0.14	-
9	NE	-	0.39	-	-
10	7581-7	-	-	-	-
11	G-1	-	0.29	-	0.34
12	447-2	0.23	0.36	0.18	0.36
13	134PLU-495	0.20	0.38	0.20	-
14	ER.SEL-495	-	-	-	-
15	797/KC-148	-	0.32	-	0.31
16	570-152	-	0.32	-	0.33
17	119PLU-283	-	0.37	-	0.36
18	335	-	-	-	-

- = Indicates absence of organic acid

As far the factors affecting the stimulation of exudates under P starvation, Ratnayake *et al.* (1978) suggested that the decrease in membrane permeability was associated with the decrease in the levels of phospholipids, resulting in a greater net leakage of amino acids and reducing sugars from the roots of sudan grass and Brazilian sour orange.

By looking many reviewed results on release of organic acid and their role in rhizosphere under P deficient condition and present investigation an attempt was made to study the role of root exudates in P uptake by different genotypes. The root exudates collected from roots of blackgram genotypes grown under deficient and sufficient P conditions, after examining (estimation) of these root exudates, release of citric acid and oxalic acid were conformed. High P uptake genotypes exudes the citric acid and oxalic acid.

4.4.1 Exudation of organic acid under P deficient condition

From the Table 21, the genotypes like DBS-14, 447-2 and 134PLU-495 secreted both oxalic acid and citric acid. DBS-21 and ER SEL-495 did not secrete any organic acids. Remaining genotypes secreted only citric acid except DBS-25 which exuded unknown organic acid.

In high P (sufficient) level, genotypes like DBS-14, DBS-24, 134 PLU 495, 797/KC-148, 570-152 and 119PLU-283 secreted traces of citric acid, the same genotypes in low P (deficient) level secreted sufficient amount of citric acid.

Only DBS-14 exuded oxalic acid in low P levels and not in high P level, 447-2 and 134PLU-495 secreted oxalic acid in both low P and high P levels but only in trace quantity.

4.4.2 Exudation of organic acid under P sufficient condition

From the Table 21, genotypes like DBS-7, DBS-14, DBS-24, G-1, 447-2, 134PLU-495, 797/KC- 148, 570-152 and 119PLU-283 secreted citric acid but only in trace quantity whereas, DBS-7, DBS-8, 447-2 and 134PLU-495 secreted traces of oxalic acid.

Table 21: Identification of organic acid exudation from roots of different genotypes under varying P levels in blackgram

SL No.	Genotype	Deficient P condition		Sufficient P condition	
		Oxalic acid	Citric acid	Oxalic acid	Citric acid
1	DBS-7	-	-	+	+
2	DBS-8	-	+	+	-
3	DBS-13	-	+++	-	-
4	DBS-14	+	+++	-	+
5	DBS-21	-	-	-	-
6	DBS-22	-	+	-	-
7	DBS-24	-	+++	-	+
8	DBS-25	+	+	+	-
9	NE	-	+	-	-
10	7581-7	-	-	-	-
11	G-1	-	+	-	++
12	447-2	*	++	+	+++
13	134PLU-495	+	++++	+	+/-
14	ER.SEL-495	-	-	-	-
15	797/KC-148	-	+++	-	++
16	570-152	-	+++	-	++
17	119PLU-283	-	+++	-	++
18	335	-	-	-	-

- = Indicates absence of organic acid + = Indicates presence of organic acid ++ = Light spot +- = Very light
+++ = Dark spot ++++ = Very dark spot * = Large spot

5. DISCUSSION

Genotypic variation in Phosphorus uptake from low Phosphorus has been reported in clover (Dunlop *et al.* 1990), sorghum and (Clark *et al.* 1986). Existence of such variability is very important to explore the possibility of selecting genotypes with desirable characters. The capacity of crop plants to access P under limiting conditions depends (other than intrinsic genetic characters) on important adoptive traits including modification in root morphological traits and exudation of organic acids etc (Schactman *et al*., 1998; Lopez Bucio *et al*., 2000).

Blackgram is one of the fourth important pulse crop in India, which is grown in low fertile and marginal land. Phosphorus is one of the major nutrients elements to maximize the productivity of leguminous crops. Blackgram is being pulse crop needs large amount of P because of its ability to fix the nitrogen from the atmosphere, required more energy (ATP and ADP). This energy has to be supplied only by more available of P in soil and the efficiency of applied P through soil is very low owing to its fixation in soil. When Blackgram grown in such situation ultimately results in to low yield. But there are some genotypes which exhibit lot of variability to over come these problems and also exhibit some morphological, physiological and biochemical adaptation.

The present investigation was conducted to identify the genetic variability present in 18 blackgram genotypes for P uptake and seed yield and its component traits under deficient P condition and in comparison with sufficient P condition. The study also included root and shoot morphological traits and their relationship with P uptake under deficient and sufficient conditions.

In deficient P condition genotypes differ in P uptake by changing their root architecture and producing different root exudates for example organic acids released from root cells, which includes low and high molecular weights of organic compounds, such as mucilages , gelatinous, amino acids, flavonoids etc.

Bhupider Shingh and Renu Panday (2002) reported that genotypes differ in magnitude of root exudation, sugars and amino acids and extent P uptake efficiency of the genotypes was positively related to exudation levels of roots. Brewsten *et al.* (1976) demonstrated that rape plants have fine roots and abundant root hairs, increased root length and number at decreasing P supply. P uptake by rape plant from flam soil which is poor in P was higher than expected on the basis of P movement to enlarged root surface (Brewsten *et al*., 1976)

The study of variance and other genetic parameters greatly help in formulating a suitable breeding programme for improvement of any crop plant, further the variability study helps to portion of the total variation present in the collection into different components viz., genotypic and environmental components.

The results obtained from the present investigation are discussed under following headings.

5.1 Analysis of variance and variability studies

5.2 Association studies

5.3 Path coefficient analysis

5.4 Mean performance of genotypes

5.5 Biochemical study

5.1 Analysis of variance and variability studies

5.1.1 Analysis of variance and variability studies of root and shoot morphological traits towards total P uptake at 45 DAS

Analysis of variance indicated presence of highly significant differences among genotypes for most of the traits except plant height and root collar diameter at 5 per cent level of probability under P deficient condition. Whereas in sufficient P condition only root volume exhibited significant different at 5 per cent level of probability and remaining traits exhibited highly significant differences among the genotypes.

Similarly at time of harvesting all traits under study showed a highly significant differences except for number of pods /plant and number of seeds per pod which showed significant differences at 5 per cent level of probability in deficient condition, where as in sufficient condition all traits showed highly significant differences

Kajjidoni *et al.* (2002) also reported significant differences in 33 blackgram genotypes for phosphorus uptake under three different P sources *i.e.,* rock phosphate, rock phosphate + P solubilizing bacteria and single super phosphate.

Analysis of variance may not reveal the absolute variability and this could be assessed through standardizing the phenotypic and genotypic variances by obtaining coefficients of variability. Thus, the components of variation such as genotypic coefficients of variation (GCV) and phenotypic coefficients of variation (PCV) were computed. Further it is essential for selection to separate out the environmental influence from the total variability. This indicates the accuracy with which a genotype can be identified by its phenotypic performance. The estimates of heritability alone fail to indicate the response to selection. Therefore, the heritability estimates appeared to be more meaningful when accompanied by estimates of genetic advance. The genetic advance as percent mean (GAM) were also estimated.

One of the way in which variability is assessed through a simple approach of examining range values. Wide range of values were observed for most of the traits under P deficient condition namely root surface area (102.5 – 1107.5 mm^2), leaf area (16.83 – 59.75 cm^2) and total P uptake (0.71 – 1.60 mg/plant) traits. Whereas in P sufficient condition lengthiest lateral root length (13.25 – 22.65 cm), leaf area (31.75 – 79.48 cm^2) and root surface area (440-1200 cm^2) and total P uptake were exhibited wide range of variability mean genotypic values.

Earlier similar observations were also made by Adepetu and Akapa (1976) in five Nigerian cowpea varieties while studying, genotypic variation for root length, total root area and total P uptake.

Magnitude of GCV estimates for P uptake and traits related to dry matter production under P stress environment suggest the need to screen the genotypes under P stress environment.

Shoot dry weight, leaf area, root surface area and total P uptake exhibited higher estimates of GCV and PCV under both P conditions. This indicates greater scope of selection for these traits and root volume exhibited higher estimates of GCV and PCV under only P deficient condition indicating greater scope for selection of this trait under deficient condition but same traits under P sufficient condition showed high PCV and moderate GCV indicating influence of environment on expression of this trait.

Plant height, root length, number of lateral roots, root dry weight and root to shoot ratio exhibited moderate GCV and PCV under both P conditions. It is interesting to note that the differences between GCV and PCV values were minimum implying the least influence of environment, indicating additive gene effects hence genotypes can be improved based on these traits.

Lengthiest lateral root length under deficient P condition and root collar diameters under sufficient P condition exhibited moderate PCV and low GCV indicating greater influence of environment on expression of these traits.

Shoot dry weight, leaf area, root surface area and total P uptake exhibited high GCV, PCV and high heritability with high GAM under both the P conditions, suggesting greater scope for direct selection for these traits and root volume exhibited high GCV, PCV and high heritability with high GAM only P deficient. Hence, selection of this trait under deficient P condition can be effective.

Similar evaluation under varying P sources done by Kajjidoni *et al.* (2002) reported that presence of large genotypic variation for root morphological traits in large accessions of blackgram. They reported that genotypes varied widely for P uptake under deficient source of P nutrition.

5.1.2 Analysis of variance and variability studies of seed yield and its components towards total P uptake at time of at the time of harvesting

Similarly, at the time of harvesting genotypes exhibited wide range of values like total P uptake (1.41-3.11 mg/plant), seed P uptake (1.03-1.73 mg/plant) and shoot P uptake (0.08-0.66 mg/plant) under P deficient condition. Whereas, in P sufficient condition seed yield (0.42-1.01 g) seed index (0.68-1.55) and shoot P uptake (0.36-1.59 mg/plant) suggested that differential uptake ability of genotypes can be exploited to identify suitable cultivars to utilize the different levels of P.

Shoot P uptake, seed yield and seed P uptake exhibited high PCV and GCV under both P condition but number of pods per plant under P sufficient condition and shoot dry weight under P deficient condition exhibited high PCV and GCV suggesting the scope for direct selection for these traits under particular P condition.

Number of pods per plant exhibited high PCV and moderate GCV under P deficient condition. Pod length and number of seeds per pod exhibited moderate PCV and low GCV indicating greater influence of environment on these traits.

Only under P sufficient condition harvest index exhibited low PCV and GCV suggested selection of this trait not effective in improvement of P uptake.

Genotypes exhibited high GCV and PCV, heritability and GAM for shoot dry weight, seed yield, shoot P uptake, seed P uptake and total P uptake among these shoot P uptake (46.19% and 44.22%) followed by seed P uptake indicating greater scope of direct selection for these traits for improvement of P uptake under deficient P condition. In sufficient condition only few traits exhibited high PCV and GCV, heritability and GAM *viz.,* shoot P uptake (49.58% and 48.97%), seed P uptake (27.50 and 27.18%) and total uptake (28.18% and 27.78%) among these, shoot P uptake is a highest, indicating greater scope direct selection for improvement these traits.

5.2 Association studies

Information on interrelationship of total P uptake with its component characters would be useful to the breeder in developing an appropriate selection strategy. Since total P uptake is a complex character and influenced by number of traits and selection based on P uptake is usually not much effective, indirect selection on the basis of desirable component characters could be of greater use. One of the objectives of present investigation was to identify the important traits associated with total P uptake under phosphorus deficit condition.

In the present investigation, results of association study have been discussed under following sub headings.

5.2.1 Association studies of root and shoot morphological traits with total P uptake at 45 DAS

Under varying P condition, total P uptake exhibited significant association with root and shoot morphological traits such as plant height, root volume, shoot dry weight, root dry weight and leaf area at both genotypic and phenotypic levels. Hence direct selection for these traits will be more useful for improvement of genotypes for higher P uptake. In sufficient condition, significant association of total P uptake with traits like root volume, root dry weight and leaf area at genotypic level and with LLRL and leaf area.

Similarly correlation of total P uptake with root dry weight and morphology was reported by Machado *et al.* (2001) in maize, Yan *et al.,* (1995a) in common bean under low and high P levels. Furlani (2002) reported high correlation of total P uptake with shoot dry weight and total dry weight in soybean for different levels of applied phosphorus. Kajjidoni *et al.* (2002) also reported high correlation of total P uptake with root and shoot dry weight in blackgram under differential levels of P.

A significant association was noticed within root morphological traits, like root surface area with root length, root dry weight with root volume at both levels and correlation of number of lateral roots with LLRL was positive significant only at genotypic level which indicates that deep rooted system tend produce more number of lateral roots there by increasing root volume and root dry weight, providing greater scope for root contact with rhizoshpere, which is particularly important for less mobile ions like P (Tara Singh and Nielson,2004) thus enhancing more amount of P uptake. This revealed that, under P deficient condition enormous amount of root growth occurred so as to adapt with P deficient (stress) condition

A significant association was observed within shoot morphological traits, like leaf area with plant height and shoot dry weight, shoot dry weight with plant height. Hence these traits can be used for identification of high P uptake genotypes under P deficient condition

Among root and shoot morphological traits a positive significant association was noticed, between root dry weight and root volume with plant height, leaf area with root dry weight and root volume. This revealed presence of a highly and good inter-relationship between root and shoot morphological traits, leading to well development root system and there by support the plant growth for obtaining more P in deficient condition.

Total P uptake exhibited high and positive significant association under P deficiency with root volume at both levels but root length did not exhibit any significant association with other traits and reduced root length was associated with increase in number of lateral roots and ultimately increase in root volume under deficient condition. Sun *et al.* (2002) studied morphology of root systems of different wheat genotypes under low P condition. They observed the number of lateral roots and root volume sharply increased under P stress. It means selection for the number of lateral roots also enhances root volume and it is easy to observes hence it was taken as main criteria so breeding for one trait can improve others also.

In deficient condition, total P uptake, exhibited high positive significant association with root dry weight at in both levels Wissuwa (2003) showed genotypic differences in p uptake from P deficient soils which was attributed to high root growth. Liao and Hong *et al.* (2001) observed genetic variation in root morphology among different genotypes in response to P availability. It reveals that there is enhanced production of root system in P deficient condition in order to meet demands of P nutrient

Total P uptake exhibited high positive significant association with shoot dry weight. All root morphological characters were responsible for high shoot growth. Hence it showed high and positive significant association with total P uptake in deficient condition at both levels but not under sufficient P condition.

Harris (1949) reported that production of good root system under P limited condition is an adaptive mechanism to aid the plant in obtaining more P per unit area. This view was

supported by Shivashankar *et al.* (1981), Foshe *et al.* (1988), Otani *et al.* (1996) and Kajjidoni *et al.* (2002) in different crop species. The exploration of soil by roots both horizontally and vertically was shown to be responsible for making a genotype more efficient.

Genotypes showed a large variation for leaf area. However, under deficient P condition leaf area was reduced drastically, some of low P uptake genotypes showed considerable reduction in leaf area under deficient condition. But some genotypes maintained relatively high leaf area and there was significant association of total P uptake with leaf area in deficient and sufficient condition at both genotypic and phenotypic levels.

These results are in agreement with Liao and Hong (2001) who observed the effect of P starvation on leaf area consistently and also several other authors reported a rapid and severe effect of P deficiency on leaf growth (Rao and Terry, 1989). Brown and Lynch (2001) showed reduction in leaf area was the major component for decrease in the total yield of leaf biomass under P deficiency.

Similarly, Brevedan *et al.* (2001) observed that low P treatment leads to reduced shoot growth significantly and the main reason being the reduction in leaf expression to an extent of 70 per cent.

Root surface area exhibited high and positive significant association with root length only under deficient condition based on correlation, the results indicated that the wide variation in root surface area among contrasting genotypes indicate the high P uptake was due to increase in root surface area under deficient condition.

Association studies revealed that root traits were strongly correlated with P uptake traits these traits can be used as indirect criteria for P uptake efficiency.

Bates *et al.* (2001) in Arabidopsis while determining the efficiency of root hairs in P acquisition at low and high P availability. They observed under high P availability that root hairs did not have any effect on plant P uptake and plant P content of three week old Arabidopsis. Under low P availability wild type Arabidopsis had greater total root surface area and high P per unit length than the mutants. It is inferred from these experiments that the response of root hairs to low P availability is an efficient strategy for P acquisition. In the same way Bates and Lynch (2000) observed in Arabidopsis, that root hairs grow longer and denser in response to low P availability. Investigations made by Schenk (1979) also showed the importance of root surface area to absorb P by studying the correlation between root surface area and P uptake.

Under deficient, total P uptake exhibited high negative significant association with root to shoot ratio in both levels but not under sufficient condition of P. It is obvious that under P deficient condition root to shoot ratio increases mainly due to increased root growth.

5.2.2 Association studies between seed yield and its components and total P uptake at time of harvesting

None of the traits in our study exhibited any significant association with total P uptake except seed yield per plant and seed P uptake mg/plant under deficient P condition at both genotypic and phenotypic levels. Whereas, under sufficient condition number of pods per plant, shoot P uptake mg/plant and seed P uptake mg/plant exhibited high positive significant association with total P uptake at both genotypic and phenotypic levels.

Total P uptake exhibited significant association with seed yield and seed P uptake which indicates direct selection for these traits will be more useful for improvement of genotypes for high P uptake. Significant association of seed P uptake with seed yield and harvest index indicates that these traits can be used for the high P uptake. A significant association of shoot dry weight with shoot P uptake, shoot dry weight was noticed only in deficient condition. Hence shoot dry weight is quite important for improvement of genotypes for high P uptake in deficient condition. In both the P conditions, harvest index exhibited significant association with seed yield. This trait indicates better sign of increased yield under

both the P conditions, means genotypes also maintain same harvest index but not yield under both the P conditions.

Seed yield per plant showed highly significant correlation with harvest index in deficient conditions. Similar results were also reported in blackgram under recommended P supply by Sagar and Sekhar (2001), Kajjidoni *et al.* (2002) and Vaithiyalingan *et al.* (2002). Hence, this character appear to be important for developing genotypes for efficient P uptake.

In sufficient P condition, seed yield and shoot dry weight both exhibited significant association with number of pods per plant indicating that these the traits can be used for improvement of genotypes under sufficient P condition. Number of seeds per pod exhibited negative significant association with number of pods per plant in both the conditions.

Inheritance of pod length is studied on the assumption that increasing the pod length will increase seed yield, but seed yield will be increased only if the longer pod has larger number of seeds or heavier seeds or a combination of both. Since seeds per pod and seed weight are primary yield components it would appear to be more productive to select for them directly (Poehlman, 1991).

Seed P uptake exhibited significant association with number of pods per plant and shoot P uptake which means that these two characters help for selection of higher P uptake genotypes under sufficient condition.

Yan *et al.* (1995b) studied genetic variation for P uptake in common bean in contrasting soil types and different P levels, where in they reported highly significant association of total P uptake with seed P uptake.

An attempt was also made to score number of favourable correlations at genotypic and phenotypic levels (Table 14 and 15) both in deficient P and sufficient P condition. Considering traits at 45 DAS, plant height (5, 5), root length (1, 1), root volume (4, 4), root dry weight (3, 3), shoot dry weight (2, 2) and leaf area (1, 1) exhibited number of favourable correlations with other traits under deficient conditions, whereas, in sufficient P condition plant height (3, 2), root length (1, 1), root volume (5, 3), root collar diameter (1, 0), root dry weight (3, 2), shoot dry weight (2, 2) and leaf area (2, 2) exhibited favourable correlations with other traits.

At the time of harvesting considering 10 traits out of these shoot dry weight (1, 1), seed yield (3, 3) harvest index (1, 1) and seed P uptake (1, 1) exhibited number of favourable under deficient condition. Whereas, in sufficient P condition, number of pods per plant (4, 2) shoot dry weight, seed yield (2, 2), shoot P uptake (2, 2) and seed P uptake (1, 1) exhibited number of favourable correlations with other traits.

Varying number of favourable correlation coefficient values were recorded between at genotypic and phenotypic levels at 45 days under sufficient P condotion indicating greater influence of environment on expression of favourable correlation among the traits.

5.3 Path analysis

The correlation coefficient indicates the relationship existing between pair of characters. But, a dependent character is an interaction of product of many mutually associated component characters and change in any one component will disturb whole network of cause and effect system. The path coefficient analysis also measure the relative importance of causal factors involved. This is simply standardized regression analysis, wherein total correlation value is subdivided into causal scheme. Li (1956) emphasized the importance of path diagram which facilitates the understanding of the nature of cause and effect system. The path analysis suggested by Dewey and Lee (1959) helps to resolve these correlations further throws more light on the way in which component traits contribute towards specifically identifying important component traits.

Table 14: Number of favourable correlations for important root, shoot morphological and P uptake traits under P deficient and P sufficient conditions at 45 DAS in blackgram

SL. No.	Character	At 45 DAS			
		50% P		100% P	
		Genotypic level	Phenotypic level	Genotypic level	Phenotypic level
1	Plant height (cm)	5	5	3	2
2	Root length (cm)	1	1	1	1
3	Lengthiest Lateral root length (cm)	2	0	1	1
4	Root volume (mm^3)	4	4	5	3
5	Root collar diameter (mm)	0	0	1	0
6	Number of Lateral roots	0	0	0	0
7	Root dry weight (g)	3	3	3	2
8	Shoot dry weight (g)	2	2	2	2
9	Leaf area $(cm)^3$	1	1	2	2
10	Root surface area (mm^2)	0	0	0	0
11	Root to shoot ratio	0	1	0	0
	Total	18	17	18	13

5.3.1 Path analysis of root and shoot morphological traits towards total P uptake at 45 DAS

Among the various traits, shoot dry weight had high positive direct effect followed by leaf area, root:shoot ratio, number of lateral roots and root volume. Out of these traits, positive significant association of total P uptake with shoot dry weight, leaf area and root volume was observed. Although, total P uptake exhibited positive significant association with plant height and root dry weight, but these had negative direct effect on total P uptake, the high positive correlation was mainly because of high positive indirect effect via shoot dry weight, leaf area and root surface area in deficient P condition at both levels. So, indirect selection for total P uptake through plant height and root dry weight could be effective for selection of genotypes for higher P uptake under P deficient condition and also for simultaneously improvement of total P uptake in deficient condition. Similar results were also reported by Vidyarani (2005).

Total P uptake exhibited high negative significant association with root:shoot ratio and it had low positive direct effect on total P uptake but its indirect effect was high negative via shoot dry weight and root volume and the ratio of root:shoot ratio was low in the present investigation, hence genotypes perform better in P deficient condition, by producing more shoot biomass. Hence, selection for high P uptake genotypes based this trait could be effective. This results supported by Buso *et al.* (1988). An efficient plant was defined as one that produced a large shoot fresh weight under low P concentrations. The butter head cultivars were the least efficient plants when grown under low P compared to the other groups, plants had lower translocation efficiency and a greater root:shoot ratio. The results of this study also demonstrate that there were genotypic variation and/or genotype × environment interaction effects for shoot weight (yield) among the lettuce cultivars grown under low P conditions imposed in the sand alumina system.

In phenotypic path, leaf area had high direct effect followed by shoot dry weight, root surface area, plant height and number of lateral roots, out of these characters, total P uptake exhibited positive significant association with leaf area, shoot dry weight, root volume and plant height. Although, significant association of total P uptake with root dry weight was observed but its direct effect was negative, the positive correlation was mainly because of high positive indirect effect via shoot dry weight, leaf area and plant height. So, indirect selection for total P uptake through root dry weight could be effective for selection of genotypes for higher P uptake under P deficient condition. Similar results were reported by Ashok (2005) in blackgram by screening for P uptake under calcareous soil.

In sufficient condition, genotypic correlation, shoot dry weight had positive direct effect on total P uptake followed by root:shoot ratio, leaf area, LLRL and number of lateral roots. Out of these traits, total P uptake exhibited significantly positive association with only leaf area and it had positive direct effect and high positive indirect effects via shoot dry weight and root length and also total P uptake exhibited positive significant association with root volume and root dry weight, these had high negative direct effect on total P uptake and Positive significant association was mainly because of high positive indirect effect via shoot dry weight, root length and leaf area indicating possibility of selection based these trait one can improve of P uptake genotypes under P sufficient condotion.

It is interesting to know that, total P uptake exhibited high negative significant association with root length but it had high negative direct effect and indirect effects on total P uptake at both levels and also total P uptake exhibited high negative significant association with LLRL and its direct effect was positive but it had high negative indirect effect through root length, root:shoot ratio and plant height, in sufficient condition at genotypic level. Indicating these two traints were not effective for improvement of genotypes for high P uptake.

In phenotypic correlation among traits, root dry weight had high positive direct effect followed by plant height and leaf area. Out of these characters, total P uptake exhibited significant association with leaf area and it had positive direct effect and its indirect effect was high positive via root dry weight, root:shoot ratio and plant height.

Table 15: Number of favourable correlations for important root, shoot morphological and P uptake traits under P deficient and P sufficient condition at the time of harvesting in blackgram

SL. No.	Character	At the time of harvesting			
		50% P		100% P	
		Genotypic level	Phenotypic level	Genotypic level	Phenotypic level
1	Number of pods/plant	0	0	4	2
2	Pod length (cm)	0	0	1	0
3	Number of seeds/pod	0	0	0	0
4	Shoot dry weight (g)m	1	1	1	1
5	Seed yield/plant	3	3	2	2
6	Seed index (g)	0	0	0	0
7	Harvest index	1	1	0	0
8	Shoot P uptake (mg/plant)	0	0	2	2
9	Seed P uptake (mg/plant)	1	1	1	1
	Total	6	6	11	8

Total P uptake exhibited significant negative association with root volume and also it had negative direct effect was high positive via shoot dry weight, root morphological trait had not much role under sufficient condotion, so that this trait can not be used for selection for high P uptake under P sufficient condition.

5.3.2 Path coefficient analysis of P uptake and seed yield and its components at the time of harvesting

In deficient P condition, among various characters seed P uptake had high positive direct effect followed by shoot P uptake and seed P uptake and seed yield exhibited positive significant association with total P uptake and their direct and indirect effects were positive at genotypic level.

At phenotypic level, seed P uptake had high positive direct effect compared to other characters and exhibited high positive significant association with total P uptake, but its indirect effect was negative. Indirect effect of seed yield was positive and exhibited positive significant association with total P uptake but direct effect was zero. Hence, selection based on this trait is not effective for improvement of P uptake.

In sufficient P condition compared to other characters, seed P uptake had high positive direct effect followed by shoot P uptake, seed index, seed yield and number of pods per plant. Out of these traits, seed P uptake, shoot P uptake and number of pods per plant exhibited positive significant association with total P uptake and also their indirect effect was positive at only genotypic level whereas at phenotypic level, seed P uptake exhibited high positive direct effect followed by shoot P uptake and these manifested high positive significant association with total P uptake and indirect effect was positive. Pariya *et al.* (1999) analysed 70 diverse genotypes of blackgram for path analysis and noticed that pods per plant, plant height and 100-seed weight had direct effect on yield. Thus maximum emphasis for selection of better genotypes should be based on pods per plant, plant height and 100-seed weight.

Number of pods per plant exhibited positive significant association with total P uptake, but its direct effect was zero and positive indirect effect was noticed for this trait.

Under these circumstances when correlation coefficient is negative but the direct effect is positive and high, restricted simultaneous selection model is to be used i.e., restrictions are to be imposed to nullify undesirable indirect effect in order to make the use of the direct effect (Singh and Kakar, 1977).

5.4 Mean performance of genotypes under deficient P condition at the time of 45 DAS

In an attempt to identify significantly superior genotypes over their respective population mean under P deficient condition, as many as eight genotypes for root dry weight, six genotypes for shoot dry weight, five each for leaf area and total P uptake, four genotypes for root surface area, two each for root volume and root length and one for lateral root length exhibited significantly superior mean performance over their respective population mean values under P deficient condition. When as under P sufficient condition, six genotypes for shoot dry weight, five genotypes each for root surface area and leaf area, four genotypes each for total P uptake and root length, two genotypes each for root dry weight and one genotypes for number of lateral root length exhibited significantly superior mean performance over their respective population mean values. One of the notable point here was none of the genotypes were significantly superior over population for root volume under sufficient P condition.

Genotypes exhibited significant differences for all characters under study at 45 DAS, out of eighteen genotypes, when top five genotypes were identified based on their mean performance for important traits *viz.,* leaf area, root surface area, root dry weight, shoot dry weight, root volume and total P uptake exhibited significant difference under P deficient

Table 16: Top five superior performing genotypes identified for root, shoot morphological and P uptake traits under P deficient condition at 45 DAS in black gram

Sl. No.	Root length (cm)	Number of Lateral roots	Root volume (mm^3)	Leaf area (cm^2)	Root surface area (mm^2)	Root dry weight (g)	Shoot dry weight (g)	Total P uptake (mg/plant)
1	DBS-21 (21.40)**	DBS-25 (8.5)*	DBS-22 (3.60)**	DBS-22 (63.28)**	134PLU-495 (1107.50)**	DBS-7 DBS-8, DBS-14 (0.22)**	DBS-22 (0.51)**	DBS-22 (1.28)**
2	134PLU-495 (20.50*)	DBS-7 (7.75)	DBS-14, DBS-21 (3.50)*	DBS-7 (59.73)**	DBS-22 (736.25)**	DBS-21, DBS-22 (0.21)**	447-2, DBS-14 (0.48)**	DBS-7 447-2 (1.08)**
3	DBS-8 (19.65)	DBS-14, G-1, 570-152 (7.50)	DBS-8 (3.0)	447-2 (45.77)**	DBS-13 (602.75)*	DBS-13 DBS-25 447- 2 (0.20)*	DBS-8 DBS-13 (0.44)**	134PLU-495 (1.05)**
4	119PLU-283 (19.25)	447-2 (7.00)	DBS-13 (2.75)	DBS-21 (43.82)**	DBS-8 (601.75)*	797/KC-148 (0.19)	797/KC- 148 (0.39)*	DBS-13 (1.01)**
5	NE (18.90)	335 (6.75)	447-2 (2.75)	DBS-14 (42.99)**	NE (510.00)	134PLU-495 (0.18)	DBS-25 NE (0.34)	DBS-21 (0.88)
Mean	17.631	6.542	2.319	35.127	477.833	0.189	0.368	0.809
CD at 5%	2.260	1.621	1.011	4.100	103.888	0.015	0.039	0.108
CD at 1%	3.105	2.227	1.389	5.633	142.709	0.021	0.053	0.148

Figures in the paranthesis indicates mean values for the character

condition. Whereas in P sufficient condition root length, leaf area, root dry weight, shoot dry weight and total P uptake exhibited significant difference.

Based on mean total P uptake of genotypes under P deficient condition *viz.,* DBS-22, DBS-7, 447-2, 134PLU-495 and DBS-13 were top performing genotypes which recorded significant superior uptake values compared to overall mean uptake, DBS-22 was the only genotype which exhibited significantly superior performance for most of traits namely leaf area, root volume, shoot dry weight, root dry weight except for root length and number of lateral roots (Plate 2). On contrary under in P sufficient condition genotypes like DBS-14, DBS-13, G-1 and DBS7 were superior for P uptake under P sufficient condition, out of these DBS-14 was the only genotype out of top five genotypes which exhibited significant performance for all traits except root length.

It is interesting to note that out of top performing genotypes for total P uptake under P deficient condition, there were as many as three genotypes common each for shoot dry weight, root dry weight, root surface area and leaf area, two genotypes for root length and two genotypes for root volume and similarly under sufficient P condition, three genotypes each for leaf area, root volume and shoot dry weight, two each for root surface area and root dry weight and one genotype for number of lateral roots were significantly superior from population mean. These results suggested that higher P uptake genotypes identified was mainly through shoot dry weight, root dry weight, root surface area and root volume traits.

However, under P deficient condition 134PLU-495 genotype exhibited significant mean performance for total P uptake, but it had not shown any significant performance for any of root morphological and other P uptake parameters except root surface area and root length (Plate 2), so the high P uptake of this genotype might be due t emergence of fine root hairs on main root as root hairs increase the effect of organic acid exudation. Similar results were also reported by earlier workers (Ellis Hoffland, 1992).

Under P deficient condition 447-2 genotype exhibited significant mean performance for total P uptake. It had not shown any significant performance for most of the traits except leaf area, root dry weight and shoot dry weight. This indicates that its high P uptake by total plant biomass, there by more expansion of leaves means 447-2 was efficient genotype in low P condition (Liao *et al.,* 2001).

DBS-13 genotype exhibited significant mean performance for total P uptake. It had shown significant performance for only root surface area, root dry weight and shoot dry weight, this revealed that higher the root surface area and root dry weight support the plant by producing more shoot growth under P deficient condition.

Similarly under P sufficient condition G-1 genotype exhibited significant mean performance for total P uptake, but it had not shown any significant performance for any of traits. This reveals that may be some other traits and some biochemical changes (exudation of organic acid) may be contributed for its high P uptake. Hence, this genotype can be used as donor for transformation of particular traits (Plate 6).

Some genotypes like DBS-7, DBS-13 and 447-2 exhibited significant mean performance over mean total P uptake under both P conditions, indicating as common genotypes under both conditions of P and these needs to be studied in greater depth (Plate 1).

Similarly genotypes like NE, 119PLU-283 and 335 were exhibited least significant mean performance over mean total P uptake under both P conditions (Plate 3).

5.4.1 Mean performance of genotypes under deficient P condition at the time of harvesting

Similar comparison made at the time of harvesting as many as six genotypes for seed yield, four genotypes each for shoot P uptake and seed P uptake, three genotypes each for

Table 17: Top five superior performing genotypes selected for root, shoot morphological and P uptake traits under P sufficient condition at 45 DAS in black gram

Sl. No.	Root length (cm)	Number of Lateral roots	Root volume (mm^3)	Leaf area (cm^2)	Root surface area (mm^2)	Root dry weight (g)	Shoot dry weight (g)	Total P uptake (mg/plant)
1	335 (26.00)**	DBS-13 (6.75)*	DBS-7 DBS-14, 134PLU-495 (4.50)	DBS-14 (79.48)**	DBS-14 (1200.00)**	DBS-7 (0.22)**	DBS-7 (0.62)**	DBS-14 (1.60)**
2	797/KC-148 (24.45)**	DBS-14 (6.50)	DBS-13, 447-2 (4.50)	447-2 (76.85)**	797/KC-148 (119.00)**	DBS-14 (0.17)*	447-2, 134PLU-495 (0.60)**	DBS-13 (1.48)**
3	ER.SEL-495 (24.35)**	570-152 (6.25)	7581-7 (4.15)	DBS-7 (76.13)**	134PLU-495 (1183.75)**	DBS-13 DBS-8 570-152 (0.16)	797/KC- 148 (0.56)**	G-1 (1.41)**
4	570-152 (23.50)*	447-2 (6.00)	ER.SEL-495 (3.90)	134PLU-495 (74.16)**	447-2 (1155.00)**	134PLU-495 (0.15)	DBS-14 (0.50)**	DBS-7 (1.29)*
5	NE (23.00)	DBS-21, DBS-25, ER.SEL-495, 797/KC-148 (5.75)	119PLU-283 (3.65)	797/KC-148 (69.73)**	119PLU-283 (1100.00)**	DBS-25 447-2 119PLU-283 (0.14)	119PLU-283 (0.49)**	447-2 (1.25)
Mean	21.214	5.319	3.594	54.369	849.389	0.141	0.437	1.097
CD at 5%	1.895	1.365	1.253	6.931	83.418	0.026	0.028	0.188
CD at 1%	2.603	1.875	1.722	9.521	114.590	0.035	0.038	0.258

Figures in the paranthesis indicates mean values for the character

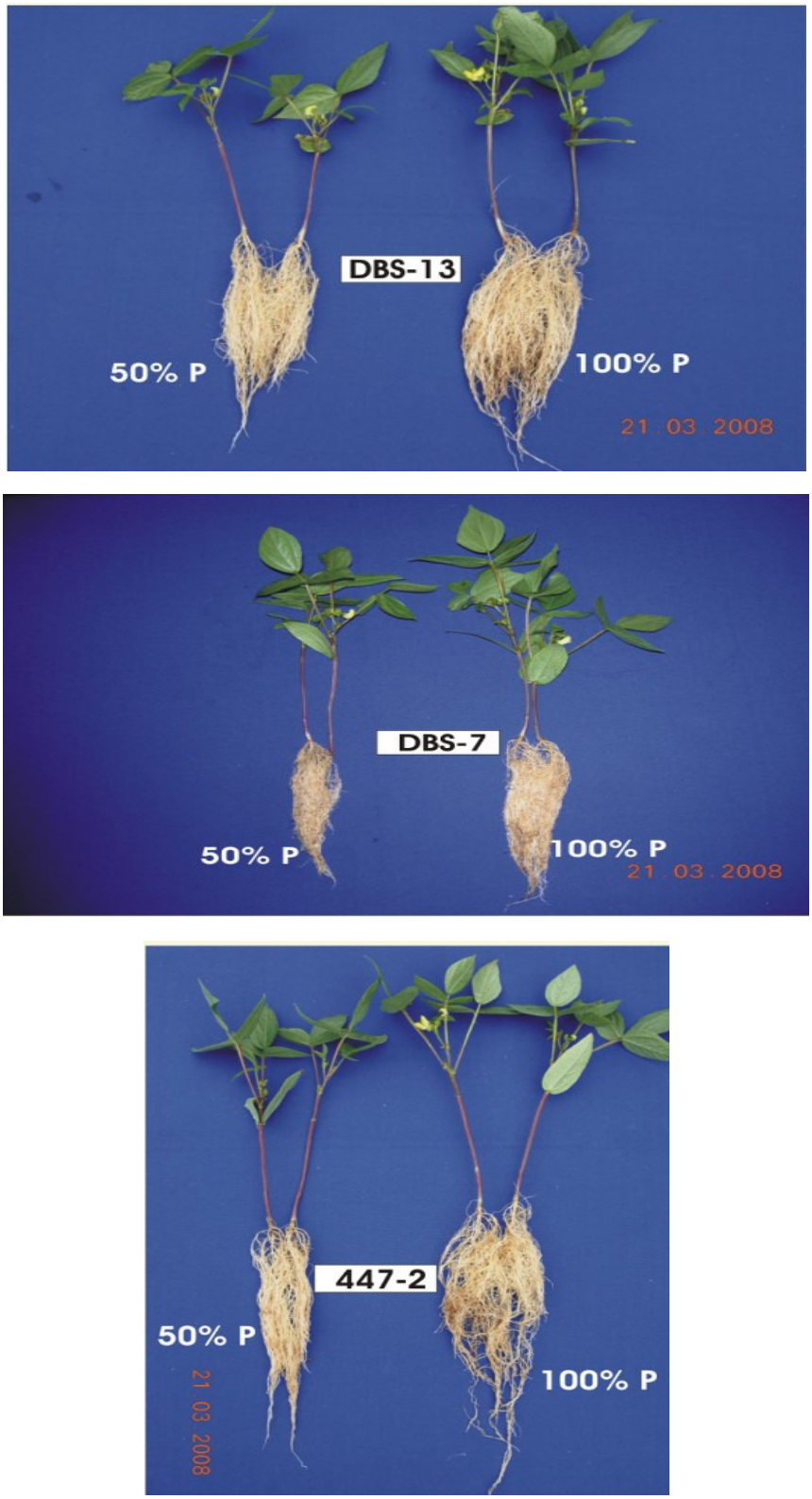


Plate.1. Comparative root and shoot morphology of genotypes with high P uptake at 45 DAS at deficient and sufficient p levels

shoot dry weight and total P uptake and one genotype each for number of pods per plant, pod length and number of seeds per pod under deficient P condition and whereas under sufficient P condition, eight genotypes for number of seeds per pod, five genotypes each for shoot p uptake and total P uptake, four genotypes each for seed yield per plant and seed P uptake, three for shoot dry weight and two genotypes each for number of pods per plant and pod length exhibited significant superior mean performance over their respective population mean.

Based on mean total P uptake of genotypes under P deficient condition, DBS-25, DBS-24, DBS-22 were top performing genotypes which recorded significant superior uptake values compared to overall mean uptake out of three DBS-25 genotype only exhibited superior performance for seed yield per plant, shoot P uptake and seed P uptake under deficient condition and on contrary under P sufficient condition genotypes like 570-152, DBS-22, G-1, 447-2 and 335 were superior for P uptake. Out of these 570-152 was only genotype which exhibited significant performance for most of traits except pod length, number of seed per pod and shoot dry weight.

Out of top performing genotypes for total P uptake under P deficient condition, as many as three genotypes for seed P uptake, two genotypes for seed P uptake and one genotypes for shoot P uptake and whereas under sufficient P condition, four for seed P uptake, three each for seed P uptake and shoot P uptake, two for number of seeds per pod and one each for number of pods per plant, pod length and shoot dry weight were superior performing genotypes.

The genotypes identified as top performing at the time of harvesting for P uptake were altogether different compared to genotypes identified at 45 DAS, indicating differential performance of genotypes for P uptake at vegetative and reproductive stages. Similar results were also expressed by Ashok (2005) in blackgram.

5.5 Biochemical studies

It was considered that root secretions contributed to the formation of an important adaptive mechanism in response to phosphorus starvation by which the plant can adjust to stress condition.

Bagayoka *et al.* (2000) in their studies on root exudation in cowpea under hydroponic experiments noticed that organic acid exudation was mainly limited to apical root zones of P deficient plants. Phosphorus application decreased the exudation of organic acids to lower levels.

Like several genotypes in our investigation, some of genotypes exuded organic acids, when lechates were examined, genotypes like DBS-13, DBS-22 DBS-25, NE and 134PLU-495 secreted only citric acid and DBS-14 exuded only oxalic acid under P deficient condition. Hence total P uptake by genotypes through the role of these organic acids. 134PLU-495 exudes some unknown (pink) organic acid under only P deficient condition (Plate 5).

Bhupinder Singh and Renu Pandey (2002) examined two maize genotypes raised under P deficient condition. The genotype showed differences in magnitude of root exudation and its sugar and amino acid content. Genotypic differences were also observed for P uptake using ^{32}P, uptake efficiency of the genotypes was positively related to exudation levels of roots.

Similarly some genotypes exuded both organic acids in both P conditions *viz.,* 447-2, 797/KC-148, 570-152, 119PLU-283, DBS-14 and DBS-24 secreted citric acid and oxalic acid but their quantity varied (Plate 4).

Results of present investigation was supported by Yasminali *et al* (1992) while determining the amount or composition of carboxylic acids in the root exudates and tissue extracts of leguminous crop plant subjected to P starvation for 3 days in water culture, detected nalonic, sucinc, fumaric, malic, citric and positive aconitic acids They also found that a large amount of these carboxylic acids especially citric and malic acids were exudated from the roots of chickpea as compared with soybean, kidney bean, cowpea and pigeonpea. The

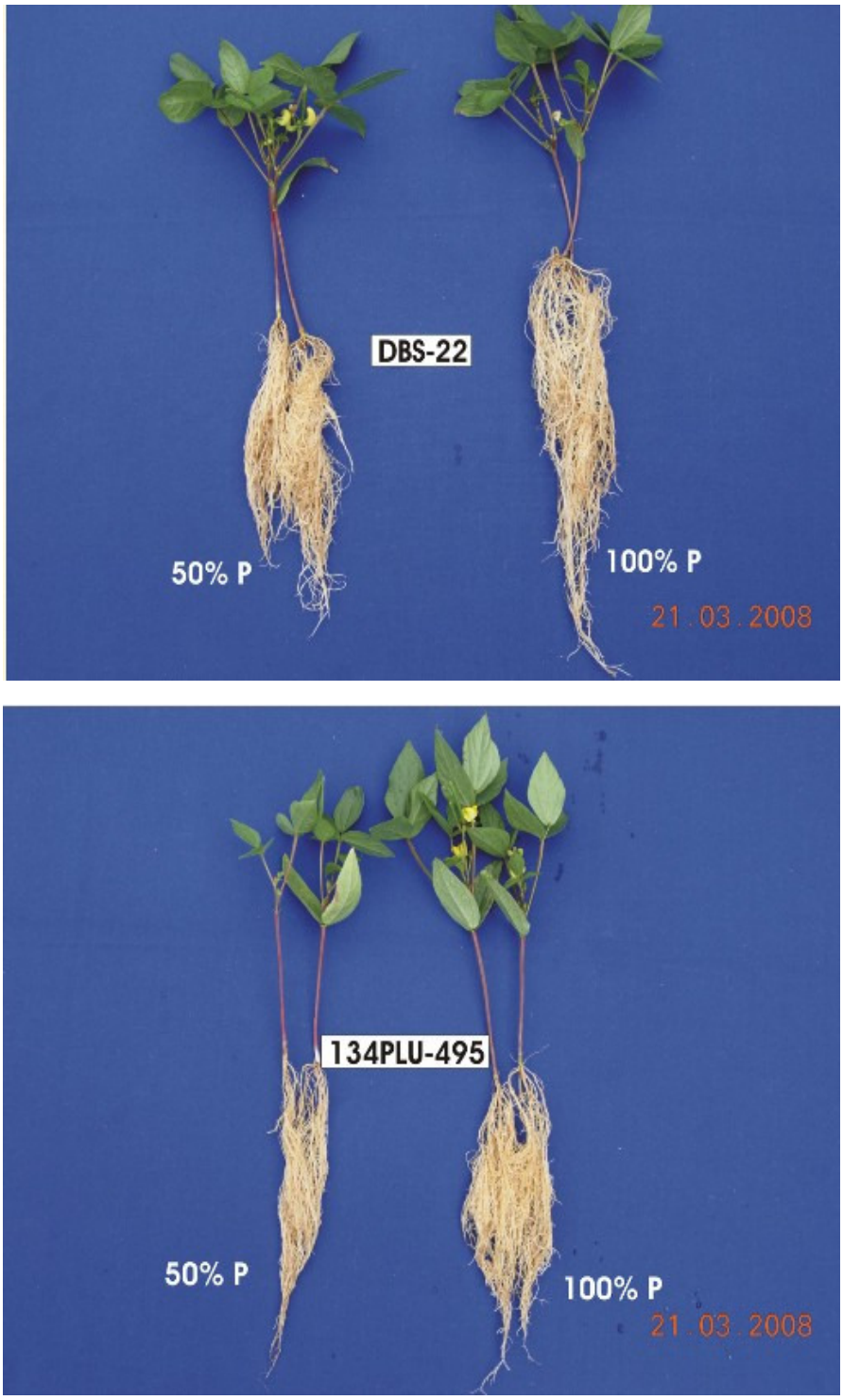


Plate.2. Comparative root and shoot morphology of genotype with high p uptake at 45 DAS under deficient p condition

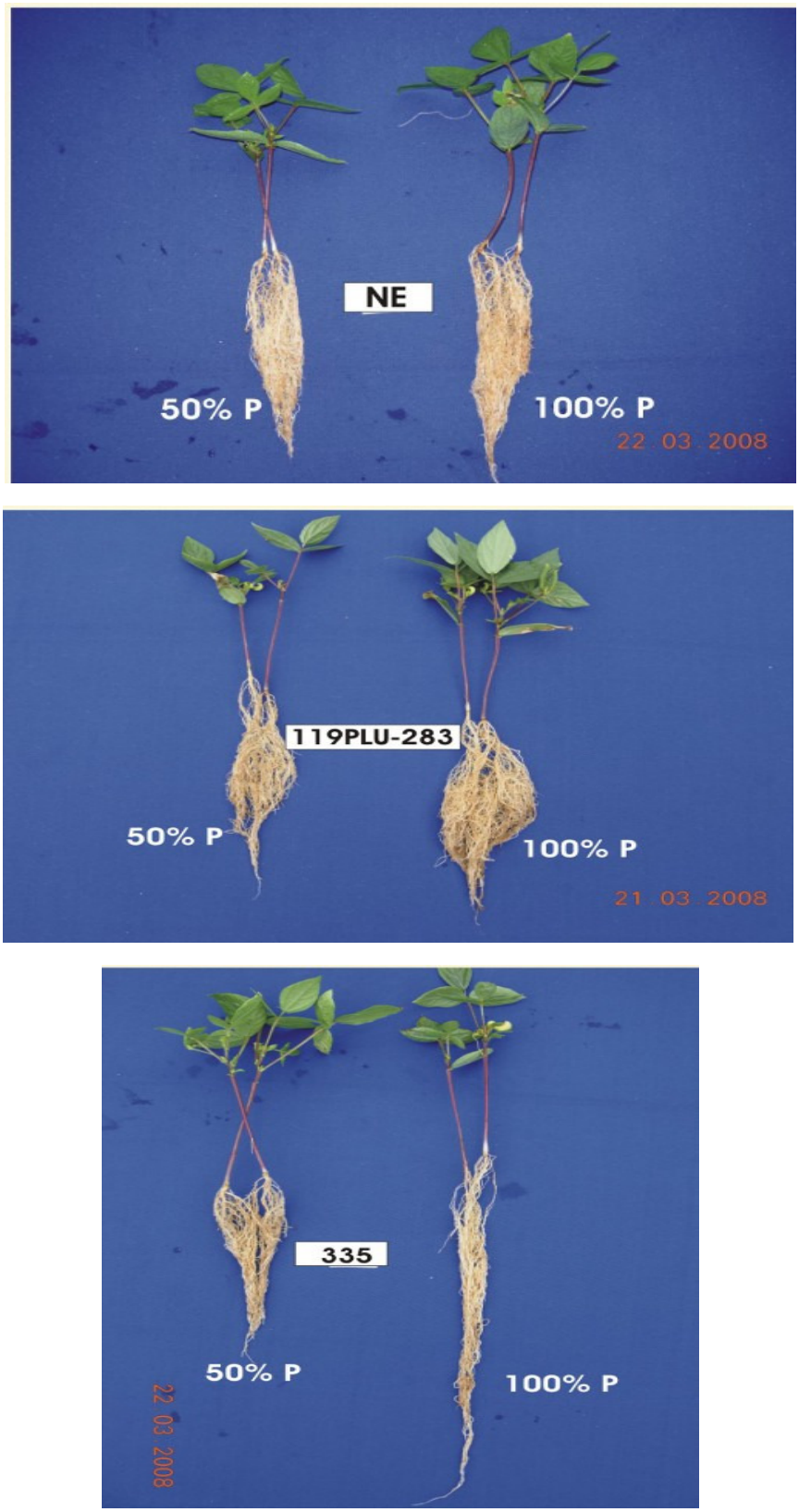
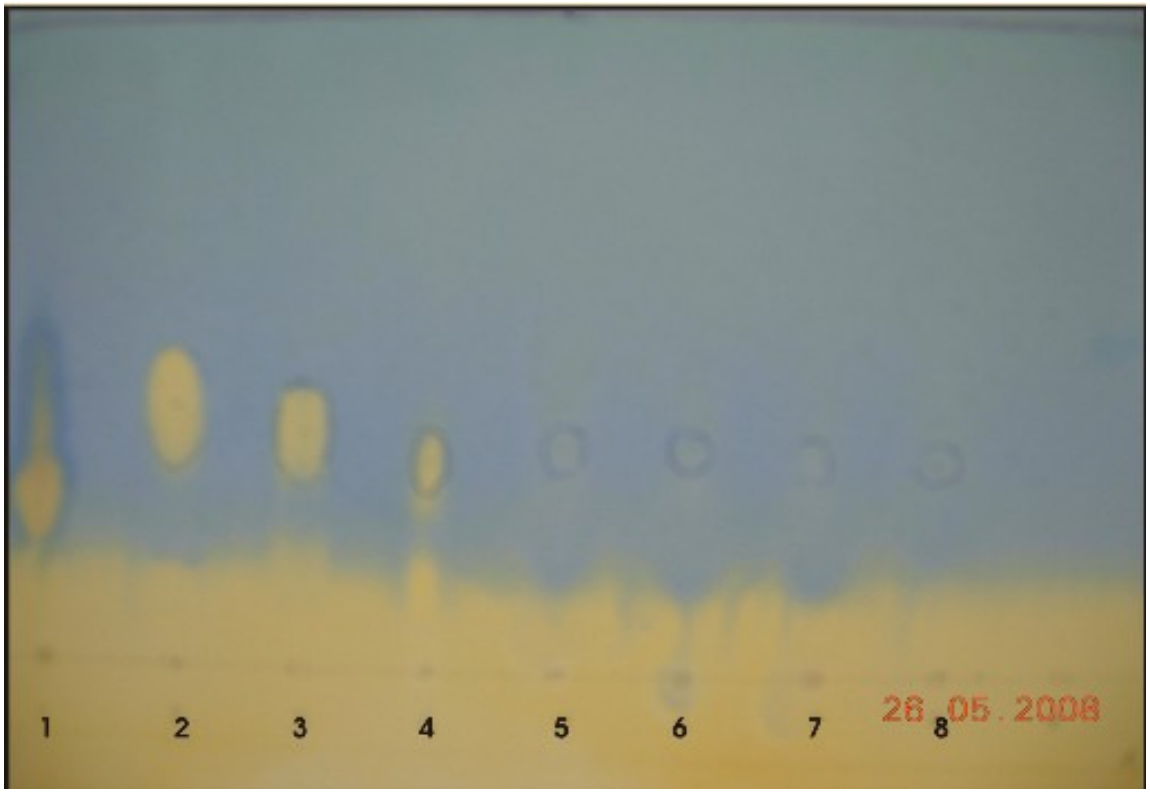


Plate.3 Comparative root and shoot morphology of genotypes with low uptake at 45 DAS at deficient and sufficient p levels

Table 18: Top five superior performing genotypes selected for seed yield, its components and P uptake traits under P deficient condition at the time of harvesting in black gram

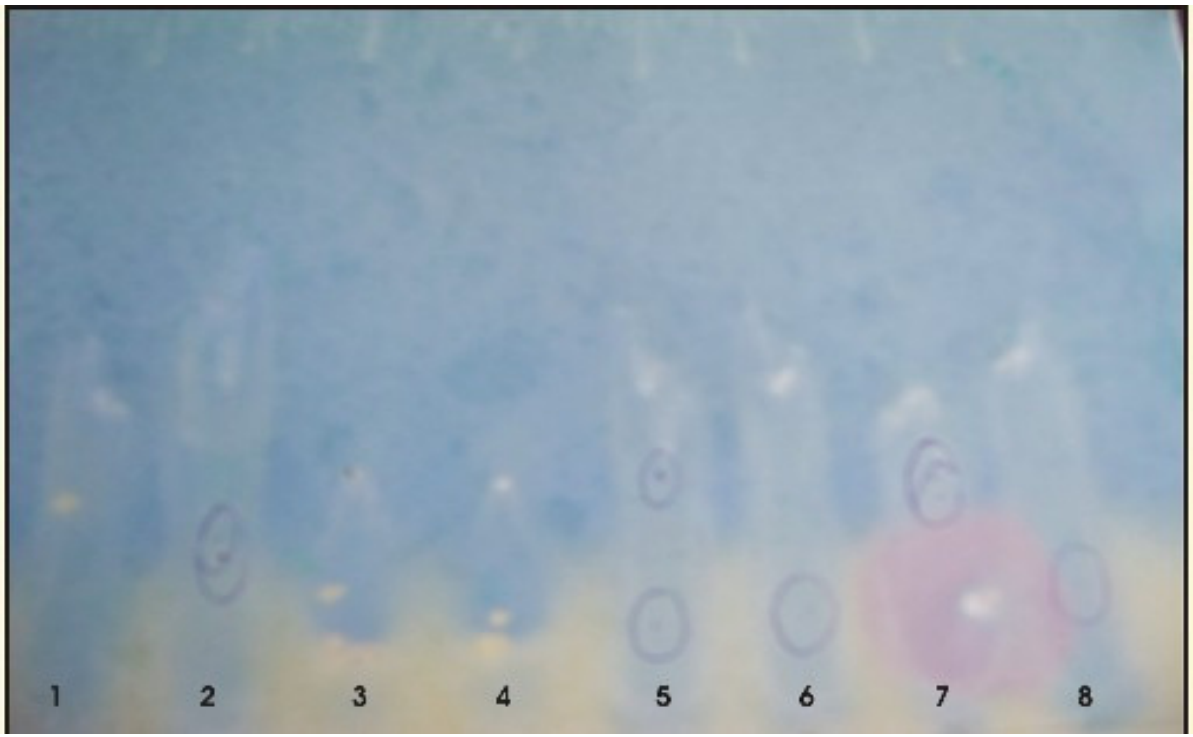
Sl. No.	Number of pods/plant	Pod length (cm)	Number of seeds/pod	Shoot dry weight (g)	Seed yield/plant	Shoot P uptake (mg/plant)	Seed P uptake (mg/plant)	Total P uptake (mg/plant)
1	NE (4.25)**	DBS-13 (4.55)**	119PLU-283 (5.50)*	DBS-7 (0.56)**	DBS-22 (0.59)**	570-152 (0.66)**	DBS-25 (2.66)**	DBS-25 (3.11)**
2	DBS-13 (3.75)	119PLU-283 (4.20)	DBS-14 DBS-25 447-2 570-152 (5.00)	570-152 (0.52)**	DBS-21 (0.51)**	DBS-25 (0.45)**	DBS-22 (2.43)**	DBS-24 (2.74)**
3	797/KC- 148 DBS-7 (3.50)	DBS-25 119PLU-283 (4.10)	DBS-8 DBS-22 (4.75)	119PLU-283 (0.44)**	DBS-14 119PLU-283 (0.50)**	119PLU-283 (0.43)**	DBS-22 (2.23)**	DBS-22 (2.46)**
4	DBS-24 (3.25)	DBS-8 (4.00)	G-1 797/KC- 148 (3354.50)	DBS-13 (0.35)	NE (0.49)**	DBS-7 (0.42)**	NE (1.73)*	NE (1.92)
5	7581-7 ER.SEL-495 119PLU-283 (3.00)	447-2 (3.95)	DBS-21 (4.25)	119PLU-283 (0.34)	DBS-25 (0.46)**	447-2 (0.34)	DBS-8 (1.69)	DBS-8 (1.90)
Mean	2.875	3.772	4.472	0.330	0.425	0.293	1.536	1.830
CD at 5%	1.017	0.543	0.906	0.048	0.022	0.082	0.163	0.164
CD at 1%	1.397	0.746	1.245	0.065	0.030	0.113	0.224	0.225

Figures in the paranthesis indicates mean values for the character



1. Ascorbic acid 2. Malic acid 3. Citric acid 4. Oxalic acid 5. 797/KC-148-50%P 6. 797/KC-148 -100% P 7.570-150-50% 8.570-150-100%P

Plate.4. Exudation of organic acids from roots of different genotypes under deficient and sufficient levels of P in blackgram



1. DBS-22-50%P 2.DBS-22-100%P 3.447-2-50%P 4.447-2-100%P 5.DBS-25-50%P 6.DBS-25-1000%P 7.134PLU-495-50% 8.134PLU-495-100%P

Plate.5. Exudation of organic acids from roots of different genotypes under deficient and sufficient levels of P in blackgram

Table 19: Top five superior performing genotypes selected for seed yield, its components and P uptake traits under P sufficient condition at the time of harvesting in black gram

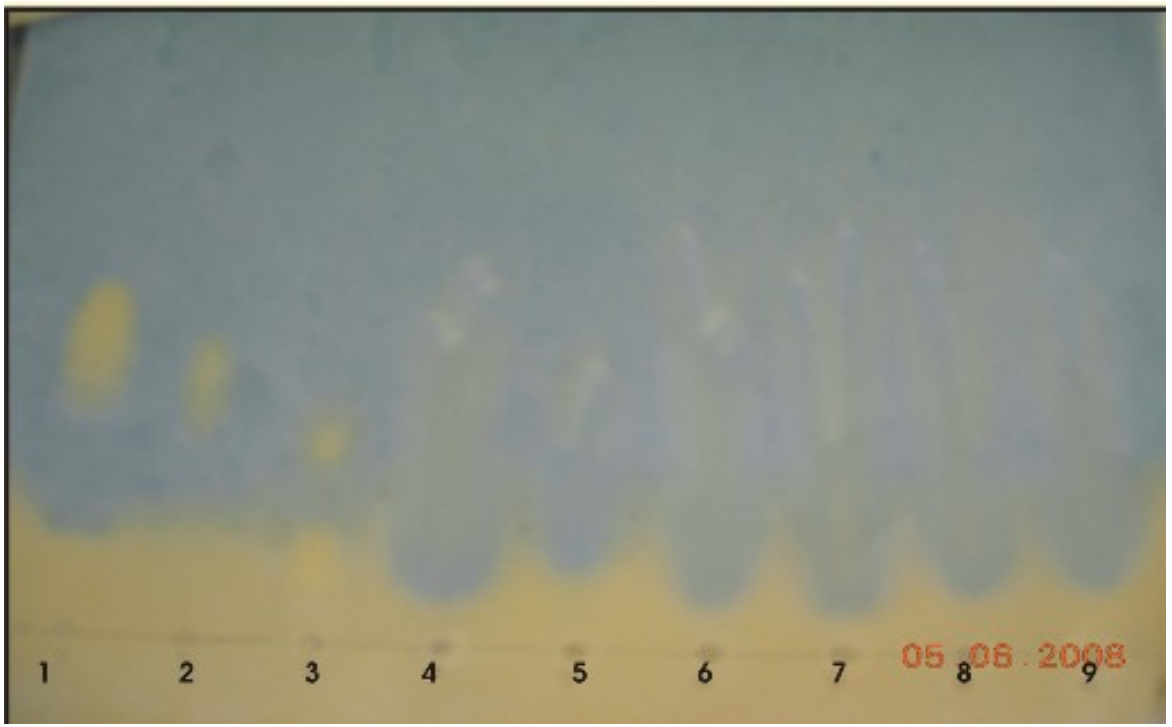
Sl. No.	Number of pods/plant	Pod length (cm)	Number of seeds/pod	Shoot dry weight (g)	Seed yield/plant	Shoot P uptake (mg/plant)	Seed P uptake (mg/plant)	Total P uptake (mg/plant)
1	570-152 (6.50)**	335 (4.45)*	DBS-8 G-1 119PLU-283 335 (5.75)*	447-2 (0.67)**	NE (1.01)**	DBS-22 (1.59)**	570-152 (4.67)**	570-152 (5.67)**
2	DBS-13 (5.10)*	7581-7 (4.40)*	DBS-14 DBS-25 DBS-21 7581-7 (5.25)*	DBS-13 (0.65)**	570-152 (0.77)**	570-152 (1.00)**	G-1 (3.61)**	DBS-22 (4.56)**
3	DBS-7 DBS-21 NE (4.25)	570-152 (4.35)	DBS-7 (5.00)	134PLU-495 (0.56)**	335 (0.75)**	ER.SEL-495 (0.96)**	447-2 (3.06)**	G-1 (4.31)**
4	ER.SEL-495 G-1 (4.00)	DBS-25 (4.15)	DBS-22 NE ER.SEL-495 (4.75)	335 (0.52)	G-1 (0.71)**	447-2 (0.86)**	335 (3.03)*	447-2 (3.92)**
5	7581-7 DBS-24 335 (3.75)	DBS-7 DBS-8 (3.10)	DBS-24 (4.50)	DBS-25 DBS-21 (0.51)	DBS-25 134PLU-495 (0.64)	DBS-13 (0.77)*	DBS-25 (2.88)	335 (3.41)
Mean	2.875	3.772	4.472	0.330	0.425	0.293	1.536	1.830
CD at 5%	1.017	0.543	0.906	0.048	0.022	0.082	0.163	0.164
CD at 1%	1.397	0.746	1.245	0.065	0.030	0.113	0.224	0.225

Figures in the paranthesis indicates mean values for the character

large amount of carboxylic acids observed in exudates of chickpea roots could not be directly correlated to the content of phospholipids in roots.

Future line of work

1. The selected genotypes can be further subjected for detailed study.
2. There is need to estimate P uptake under hydrophonics for confirmation of secretion of organic acids in P deficient condition and genes responsible for these organic acid should be identified.
3. There is need to find out QTLs for root traits and P uptake.



1. Malic acid 2.Citric acid 3. Oxalic acid 4.DBS-14-50%P 5.DBS-14-100%P 6.DBS-24-50%P 7.DBS-24-100%P 8.G-1-50%P 9.G-1-100%P

Plate.6. Exudation of organic acids from roots of different genotypes under deficient and sufficient levels of P in blackgram

6. SUMMARY AND CONCLUSIONS

An experiment was conducted to assess genetic variability present among the 18 genotypes for P uptake along with root and shoot morphological, seed yield and its components under P deficient and sufficient condition and at 45 DAS and at the time of harvesting at College of Agriculture, Dharwad. The data were subjected for analysis of variance, association analysis and path coefficient analysis.

Plants have developed several adaptive strategies to enhance the availability and uptake of P in response to persistent P deficiency. These adaptive strategies could be physiological, biochemical at the molecular level. Amongst these mechanisms, increase in root growth, root volume, number of lateral roots, root surface area, leaf area and exudation of organic acids are known to play a vital role in aiding plants to acquire more P under P deficient condition.

Brief summary of results obtained are presented below.

1. Analysis of variance under both P conditions indicated presence of significant differences among genotypes for all twelve traits at 45 DAS and ten traits at harvesting time.

2. Twelve characters at 45 DAS exhibited wide range of values, like root length, root volume, number of lateral roots, leaf area and root surface area were showed wide range of values under both P conditions.

3. Similarly at the time of harvest traits like number of seeds per pod, seed yield, shoot P uptake, seed P uptake and total P uptake under deficient condition except seed index under P sufficient condition also exhibited wide range of values.

4. Genotypes exhibited higher estimates of GCV and PCV under both P conditions at 45 DAS, except for plant height, root length, number of lateral roots and root to shoot ratio were exhibited moderate PCV and GCV under both P conditions. Root volume exhibited high PCV and moderate GCV only under P sufficient condition. LLRL under P deficient condition and root collar diameter under P sufficient condition exhibited moderate PCV and low GCV.

5. Similarly at the time of harvesting majority of traits exhibited high GCV and PCV except for seed index under both P conditions, harvest index only under P deficient condition and shoot dry weight only under P sufficient condition exhibited moderate GCV and PCV and harvest index exhibited low GCV and PCV only under P sufficient condition. Traits like pod length and number of seeds per pod under both condition exhibited moderate PCV and low GCV under both conditions.

6. At 45 DAS traits like shoot dry weight, leaf area, root surface area and total P uptake under both P condition except root volume under P deficient condition were exhibited high GCV and PCV and high heritability with high GAM

7. At the time of harvesting seed yield per plant, shoot P uptake, seed P uptake and total P uptake exhibited high GCV, PCV and high heritability with high GAM under both P condition and shoot dry weight exhibited high GCV, PCV and high heritability with high GAM under only P deficient condition.

8. In deficient condition, total P uptake at 45 DAS exhibited significant association with plant height, root volume, root dry weight, shoot dry weight, leaf area and root surface area. In sufficient condition, total P uptake exhibited significant association with root volume, root dry weight and leaf area at genotypic correlation and correlation of total P uptake with root volume and leaf area was positive significant at phenotypic correlation.

9. At the time of harvesting only two characters exhibited significant correlation with P uptake *viz.,* seed yield per pod and seed P uptake at both genotypic and phenotypic levels under P deficient condition where as under P sufficient condition a significant association of total P uptake with number of pods per plant, shoot P uptake and seed P uptake at both correlations.

10. Path analysis indicated differential path of productivity particularly under P deficient condition leaf area (at genotypic level) and shoot dry weight (at phenotypic level) at 45 DAS had high direct effect contribution with significant correlation with total P uptake but under sufficient P condition shoot dry weight (at genotypic level) and root to shoot ratio (at phenotypic level) had high direct contribution for total P uptake.

11. At the time of harvest in both P conditions seed P uptake had high direct effect at both genotypic and phenotypic levels

12. Mean performance of genotypes for P uptake varied at 45 DAS the genotypes namely DBS-22, DBS-7, 447-2, 134PLU-495, DBS-13 and DBS-21 were superior for higher P uptake under P deficient condition. Whereas, under P sufficient condition DBS-14, DBS-13, G-1, DBS-7 and 447-2 were superior for higher P uptake.

13. Similarly at the time of harvesting DBS-25, DBS-24, DBS-22, NE and DBS-8 were superior for high P uptake under P deficient condition and genotypes like DBS-14, DBS-13, G-1, DBS-7 and 447-2 were superior for higher P uptake under P sufficient condotion.

14. After examination of root exudation from the roots at 30 DAS, genotypes like DBS-13, DBS-22 DBS-25, NE and 134PLU-495 (exudes some pink unknown organic acid) secreted only citric acid under P deficient condition. Where as in sufficient condition DBS-7, DBS-14, DBS-24, G-1, 447-2, 134PLU- 495, 797/KC- 148, 570-152 and 119PLU-283 secreted citric acid but only in trace quantity and DBS-7, DBS-8, 447-2 and 134PLU-495 also secreted traces of oxalic acid.

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APPENDIX

Appendix I: Typical physical properties of exfoliated vermiculite

Colour	Light to dark brown
Shape	Shaped granules
Bulk density (mg/m^3)	100-150 kg/cum
Combustibility	Non-combustible
Sintering temperature	$1150\text{-}125^0$ ded C
Fusion point	$1200\text{-}132^0$ ded C
Cation exchange capacity	50-150 me/100 g
Specific heat	0.84-1.08 kj/kg K
	0.20-0.26 kcal/kg K
	0.20-0.26 Btu/lb deg F

GENETIC VARIATION FOR PHOSPHORUS UPTAKE IN SELECTED GENOTYPES OF BLACKGRAM (*Vigna mungo* L. Hepper)

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ABSTRACT

Blackgram is one of the fourth important pulse crops in India, which is grown in low fertile and marginal land. Phosphorus is one of the major nutrient elements to maximize the productivity of leguminous crops. But, the major problem is the uptake of applied P by plants through soil is very low owing to its fixation in soil. Genotypes exhibit variability for plant morphological, physiological and biochemical attributes under varying P levels. Therefore, a study was conducted during summer 2007 at UAS, Dharwad to estimate genetic variability for P-uptake in pot culture using vermiculite with eighteen genotypes under P-deficient and P-sufficient conditions. Shoot dry weight, leaf area, root surface area and total P-uptake under both P conditions and root volume under only P deficient condition at 45 DAS. Shoot P uptake, seed P uptake and total P uptake at the time harvesting exhibited high GCV, PCV and high heritability with high genetic advance over mean. Total P uptake exhibited significant association with root volume, root dry weight and leaf area under both P-conditions and with plant height and root surface area under only deficient condition at 45 DAS. At the time of harvest, seed yield/plant and seed P-uptake under P-deficient condition and number of pods/plant, shoot and seed P-uptake under P sufficient condition exhibited significant association with total P uptake.

Path coefficient analysis revealed that total P uptake had high direct positive effect by leaf area under P deficient condition and shoot dry weight under P sufficient condition at 45 DAS. At the time of harvesting under both P conditions seed P uptake had high direct effect on total P uptake. Biochemical study revealed that root exudates citric and oxalic acid under both the P conditions, but large amount of acids exudated only under P deficient condition.