YIELD AND SEED QUALITY OF GROUNDNUT AT DIFFERENT LEVELS OF PHOSPHORUS AND CALCIUM FERTILIZER

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CERTIFICATE

This is to certify that the thesis entitled ***"YIELD AND SEED QUALITY OF GROUNDNUT AT DIFFERENT LEVELS OF PHOSPHORUS AND CALCIUM FERTILIZER"*** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (MS)*** *in* ***SEED TECHNOLOGY****, embodies the result of a piece of bona fide research work carried out by* ***PRITY CHOWDHURY****, Registration No.* ***15-06505,*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has duly been acknowledged.

Dated:
Place: Dhaka, Bangladesh

Prof. Dr. Tuhin Suvra Roy
Supervisor
Department of Agronomy

Dedicated to My Nurturers, Especially My Parents

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ABSTRACT

The experiment was carried out at the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during April 2021 to August 2021 to determine the effect of phosphorus and calcium on yield and seed quality of groundnut. The experiment consisted of two factors. Factor A: Phosphorus fertilizer (4 levels) viz., P_1= 0 kg P ha^{-1} (0 kg TSP ha^{-1}), P_2= 29 kg P ha^{-1} (145 kg TSP ha^{-1}), P_3= 32 kg P ha^{-1} (160 kg TSP ha^{-1}) and P_4= 35 kg P ha^{-1} (175 kg TSP ha^{-1}) and factor B: Calcium fertilizer (4 levels) viz., Ca_1= 0 kg Ca ha^{-1} (0 kg gypsum ha^{-1}), Ca_2= 55 kg Ca ha^{-1} (275 kg gypsum ha^{-1}), Ca_3= 60 kg Ca ha^{-1} (300 kg gypsum ha^{-1}) and Ca_4= 65 kg Ca ha^{-1} (325 kg gypsum ha^{-1}). The experiment was laid out in split-plot design with three replications. Results indicated that, different levels of phosphorus and/or calcium had significant influence on most of the growth, yield and yield contributing characters and seed quality of groundnut. Results revealed that most of the yield and seed quality parameters gradually increased with increasing phosphorus level upto P_3 (32 kg P ha^{-1}) levels. Thereafter P_3 (32 kg P ha^{-1}) and P_4 (35 kg P ha^{-1}) showed statistically similar results. In case of calcium application, similar trend of yield and seed quality parameters were also observed in this study. In case of combined effect of phosphorus and calcium application, the maximum pod yield (2.36 t ha^{-1}), seed yield (1.79 t ha^{-1}), protein content (39.63%), oil content (48.25%), vitamin E content (9.69 mg 100 g $seed^{-1}$) and germination (90.70%) were recorded from P_4Ca_3 (32 kg P ha^{-1} with 60 kg Ca ha^{-1}) treatment combinations. On the other hand the minimum pod yield (1.44 t ha^{-1}), seed yield (0.91 t ha^{-1}), protein content (29.41%), oil content (32.41%), vitamin E content (4.97 mg 100 g $seed^{-1}$) and germination (76.60%) were recorded from P_1Ca_1 (control) treatment combinations. So, concluded from the study that the treatment combination P_4Ca_3 (groundnut growing on 32 kg P ha^{-1} with 60 kg Ca ha^{-1}) was found to be most suitable combination for the potential pod yield, seed yield and seed quality of groundnut.

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LIST OF ACRONYMS

ACRONYM		FULL MEANING
AEZ	=	Agro-Ecological Zone
%	=	Percent
°C	=	Degree Celsius
B	=	Boron
BARC	=	Bangladesh Agricultural Research Council
BARI	=	Bangladesh Agricultural Research Institute
BCSRI	=	Bangladesh Council of Scientific and Industrial Research
cm	=	Centimeter
CV%	=	Percentage of coefficient of variance
cv.	=	Cultivar
DAS	=	Days after sowing
et al.	=	And others
FAO	=	Food and Agriculture Organization
g	=	Gram
ha^{-1}	=	Per hectare
kg	=	Kilogram
LSD	=	Least Significant Difference
MoP	=	Muriate of Potash
N	=	Nitrogen
No.	=	Number
NPK	=	Nitrogen, Phosphorus and Potassium
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resource and Development Institute
t	=	Ton
TSP	=	Triple Super Phosphate
viz.	=	Videlicet (namely)
Wt.	=	Weight

CHAPTER I

INTRODUCTION

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INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a self-pollinated, annual, herbaceous, autotetrapliod legume with 2n=40 chromosomes belonging to the family leguminoseae (Fabaceae). It was thought to have originated in South America. Groundnut is one of the principal economic crops of the world that ranks 13^{th} among the food crops (Mouri *et al*., 2018). It is known by various names as "wondernut", "Poor man's Cashewnut", "Peanut" "Monkey nut", "Earth nut" or "*King of Oilseeds*" (Annadurai and Palaniappan, 2009). It is the thirteenth most important food crop of the world; fourth most important source of edible oil and the third most important source of vegetable protein (Sorrensen *et al*., 2004; Taru *et al*., 2008). This crop has own importance due to high edible oil content and nutritional value of kernel as human food, and haulm as rich feed for animals. Globally, 50% of groundnut production is used for oil extraction, 37% for confectionary use, and 12% for seed production (Shendage *et al*., 2018). Peanut is very important source of oil (40-45%), protein (26%), carbohydrates (25%), minerals (Phosphorus, calcium and iron) and vitamins (vitamin B complex like thiamine, riboflavin, niacin and vitamin E) in addition to higher proportion of unsaturated fatty acids, including essential fatty acids like linolenic and linoleic acids (Oyewole *et al.*, 2020). The importance of groundnut in the global economy is rapidly increasing due to its demand as oil for making margarine, cooking oil, soaps, and a variety of other household products (Vessey and Buss, 2002).

In Bangladesh, it is popularly known as ''cheenabadam''. Aside from its nutritional value, groundnut is a major oil seed crop. Groundnut is grown on 30791 hectares with a production of 55108 metric tons during Rabi and Kharif seasons in Bangladesh (BBS, 2020).

Groundnut is a major crop in the char lands of Bangladesh, but because of poor yields, farmers derive a limited income from the crop. The productivity of groundnut depends on proper selection of variety, fertilizer management, environmental factors, metal contents in soil and other management practices (Uddin *et al.,* 2016). Balanced use of fertilizers is said to play an important role in sustainable crop production (Afridi *et al.*, 2002). A good crop production would depend upon the time and appropriate amount of fertilization (Laharia *et al.*, 2015). One of the important factors influencing the production of crops in the tropics is soil fertility such that soil productivity is hampered by the deficiencies of nutrients such as nitrogen, phosphorus and potassium (Wandahwa *et al.*, 2006). One of the important nutrients in groundnut production is phosphorus because of its large effects on seed oil content, and as such, phosphorus in excess or deficiency may reduce oil percentage (Krishnappa *et al.*, 1994).

Phosphorus (P) is the second major essential nutrient element for crop growth and good quality yield. The most obvious effect of P is on the plant root system. The requirement of P in nodulating legumes is higher compared to non-nodulating crops as it plays a significant role in nodule formation and fixation of atmospheric nitrogen (Afridi *et al*., 2002). Due to the important role played by P in the physiological processes of plants, application of P to soil deficient in this nutrient leads to increase groundnut yield (Kabir *et al*., 2013). Phosphorus is critical in plant metabolism which plays an important role in cellular energy transfer, respiration, photosynthesis and it is a key structural component of nucleic acids coenzymes, phosphorproteins and phospholipids. Due to the important role played by P in the physiological processes of plants, application of P to soil deficient in this nutrient leads to increase groundnut yield. Phosphorus deficiency results in poor root development, poor pod setting and subsequently reduces pod yield (Jain *et al*., 1990). Phosphorus plays an important role on number of nodules production, nodules dry weight and uptake of N, P and K (Ramesh *et al*., 1997).

Calcium (Ca) is a critical element that plays key structural and signaling roles in plant growth. In addition to its role in the cell wall structure and function, it helps in cell wall strengthening, cell extension, cell division, osmoregulation, and the modulation of certain enzymes (Marschner, 1995; White and Broadley, 2003; Hawkesford *et al.*, 2012). The peanut is unique, as the pods directly absorb most of the calcium, and therefore calcium fertilizers are applied in the pod zone at the peak flowering stage to ensure its availability to the pods (Janila *et al.*, 2013). The availability of calcium in the peanut pod zone is one of the most significant soil fertility factors affecting the success of reproductive growth of peanuts and, as a result, pods and kernel yields (Gascho and Devis, 1994; Zharare *et al.*, 2009). Different forms of Ca^{2+} fertilizers, such as gypsum ($CaSO_4$), limestone ($CaCO_3$), and nano calcium forms are available for soil amendment to supplement soil Ca^{2+}. Several authors have shown the importance of different calcium forms in the growth and productivity of peanuts (Wiatrak *et al.*, 2006; Bairagi *et al.*, 2017). Thilakarathna *et al.* (2014) found that the addition of 250 kg ha^{-1} of gypsum increased the pod dry weight of peanuts by 39%. Furthermore, the application of gypsum at 200 kg ha^{-1} significantly increased peanut growth parameters and yield (Yadav *et al.*, 2015). Arnold *et al.* (2017) also indicated that the peanut cultivar and gypsum application rate had effects on seed Ca^{2+} concentration, which increased as the field gypsum application rate increased. Calcium deficiency is recognized as an important problem in peanut production, being associated with pod rot and poorly filled pods (Gascho and Davis, 1994; Pattee and Stalker, 1995). Peanuts reproduce via geocarpy (Pathak, 2010). However, the Ca^{2+} nutrition of peanuts is complicated by the geocarpic nature of the plant and by the immobility of Ca^{2+} in the phloem, which restricts the redistribution of Ca^{2+} from older to younger tissues within the plant via the phloem (Marschner, 1995). Peanuts lacking Ca^{2+} may form undeveloped pods called “pops”, or have poor germination and vigor. Pods must obtain Ca^{2+} from the surrounding soil, because Ca^{2+} is generally immobile in the phloem. Adequate Ca^{2+} in the pegging zone is essential for proper peanut development. During the development of peanut pods, more than 90% of the total required Ca^{2+} is absorbed. The insufficient Ca^{2+} supply may result in a large number of empty pods, undeveloped pods, final low yield, poor quality seeds, and darkened plumule or black hearts, which can adversely affect seed viability and germination rates (Yang, 2015). However, Yang *et al.* (2020) reported that Ca^{2+} deficiency is the main cause of empty pods in peanuts. In addition, the lack of calcium can lead to embryo abortion, empty pod formation, and massive reductions in yields.

Therefore, this study was aimed to examine the effect of phosphorus and calcium on growth, yield and seed quality of groundnut. Under the above circumstances, the present experiment was undertaken with the following objectives:

1. To observe the effect of phosphorus and/or calcium on growth, yield and seed quality of groundnut, and
2. To find out the suitable combination of phosphorus and calcium for better yield and good quality seed of groundnut.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Growth, yield and seed quality of groundnut are considerably depended on manipulation of different macronutrients management for obtaining higher production and quality seed. Among the mentioned different macronutrients, phosphorus is responsible for the growth, yield and seed quality of groundnut. As well as calcium is also responsible for the growth, yield and seed quality of groundnut. In this section, an attempt was made to gather and study relevant information accessible in the country and worldwide in order to gain knowledge that would be useful in performing the current research and then writing up the results and discussion.

2.1 Effects of phosphorus on groundnut

Everest *et al.* (2022) conducted a field experiment entitled "effect of phosphorus fertilization on yield, nutrient acquisition, use efficiency and bio-chemical compositions of groundnut" in summer seasons of 2016 and 2017, using split plot design with three varieties ('JL-24', 'Gangapuri', 'TAG-24') in main plot and four fertilization levels (0, 40, 60, 80 kg P_2O_5 ha^{-1}) in sub plots. The study revealed that pod yield enhanced significantly by 15.4%, 27.3% and 39.9% with increase in fertilization rates from 40 kg to 80 kg ha^{-1} compare to unfertilized plots. Protein and oil content showed a positive response with phosphorus application. Agronomic efficiency, recovery efficiency and utilization efficiency were also increased with phosphorus rates, whereas, partial factor productivity, agro-physiological efficiency and physiological efficiency had decreasing trends. 'Gangapuri' gave higher pod yield (1.80 t ha^{-1}), protein (24.27%) and oil (45.41%) content than other selected varieties. Enhanced phosphorus rate also increases nutrient uptake in groundnut.

LincoIn *et al.* (2022) conducted a field experimental trail to evaluate the effect of zinc and phosphorus on growth and yield of groundnut. The experiment was laid out in Randomized Block Design (RBD) with ten treatments replicated thrice. In the view of this experiment, zinc and phosphorus were applied thrice at different levels ($ZnSO_4$ at 10, 20, 30 kg ha^{-1} and P at 20, 40, 60 kg ha^{-1} respectively) along with RDF and control plot with RDF alone. Results revealed that growth parameters at 60 DAS and yield parameters at harvest *viz*., plant height (24.13 cm), number of nodules $plant^{-1}$ (180.53), plant dry weight (59.10 g), number of pods $plant^{-1}$ (27.53), number of kernels pod^{-1} (2), seed index (39.77 g), shelling percentage (69.90%), pod yield (3 t ha^{-1}), seed yield (2.10 t ha^{-1}), haulm yield (3.35 t ha^{-1}) and harvest index (32.10%) were recorded significantly higher with the application of $ZnSO_4$ 30 kg ha^{-1} + Phosphorus 60 kg ha^{-1} as compared to other treatments.

Naabe *et al.* (2021) conducted a study on the experimental field of the University for Development Studies, Nyankpala in the Northern region of Ghana to evaluate the interactive effect of three P rates (0, 30 and 60 kg P_2O_5 ha^{-1}) and three IR rates (0, 3 and 6 g kg^{-1} seed) on groundnut yield and to assess the economic viability of these technologies to farmers. The study was conducted using a 3 × 3 factorial laid out in a randomized complete block design with three replications. Nodule count and pod number per plant were significantly affected by P fertilizer rates (PR) and rhizobium inoculant rates (IR) interaction. The effects of PR and IR significantly increased grain yield of groundnut, with 60 kg P_2O_5 ha^{-1} and 6 g inoculant kg^{-1} seed recording the highest grain yield of 2708.3 and 2376.6 kg ha^{-1} respectively. Correlation analysis suggested that major determinants of groundnut grain yield were nodule count, effective nodule count, pod number and pod weight. Gross benefits were higher in treatment with P fertilizer and/or inoculant application. Estimated B/C ratios also indicated that, compared to the control, all the treatments are attractive. Therefore, cultivating groundnut by using P fertilizer and/or inoculant may provide the most economically viable and low-risk options for increasing groundnut yield in northern Ghana.

Meresa *et al.* (2020) conducted a field experiment at Sheka-Tekli in 2017/18 cropping season to investigate the response of groundnut genotypes to combined application of phosphorus and zinc on yield and nutritional contents. Adequate phosphorus (P) and foliar zinc (Zn) in groundnut required for obtaining Zn-enriched grain and optimum yield. The treatments were consisted of three groundnut genotypes (ICGV00308, ICGV91114 and Sedi) as main plot and four combined PZn fertilizer levels (00), 10 kg P ha^{-1} + 0.50 g Zn L^{-1}, 20 kg P ha^{-1} + 1 g Zn L^{-1} and 30 kg P ha^{-1} + 1.5 g Zn L^{-1} as sub plot were assigned in split plot design with tree replications. The result indicated that yield and yield components respond significantly to the main and interaction effects. The highest significant seed yield (2529 kg ha^{-1}) and protein content (37.79%) were obtained in response to the application of $P_{30}Zn_{1.5}$ fertilizer on sedi variety in the loamy sand soil. The percentage of crude protein and fat content had significantly affected by interaction components. Most of the yield component traits showed strong positive correlation with seed yield. While the lowest seed yield was recorded from ICGV00308 without fertilizer. The highest fat content (43.95%) was gained from genotype ICGV00308 at $P_{30}Zn_{1.5}$ fertilizer. From the interaction of sedi with $P_{30}Zn_{1.5}$ fertilizer was recorded highest protein content. Based on economic analysis the highest MRR (380.58%) was obtained from ICGV00308 genotype at $P_{10}Zn_{0.5}$ fertilizer. From the result of the study, application of PZn fertilizer increases seed yield of groundnut. Therefore, based on the MRR result ICGV00308 genotype at $P_{10}Zn_{0.5}$ fertilizer was optimum for groundnut production in the study area and similar agro-ecologies.

Sharma *et al.* (2020) conducted a field experiment at Agronomy farm, S.K.N. College of Agriculture, Jobner (Rajasthan) during *kharif* season of 2017 on loamy sand soil. The experiment was laid down in randomized block design with eleven phosphorus management treatments (Control, 100% RDF, 75% P through inorganic + 25% through FYM, 75% P through inorganic + 25% through VC, 75% P through inorganic + 25% through PM, 50% P through inorganic + 50% through FYM, 50% P through inorganic + 50% through VC, 50% P through inorganic + 50% through PM, 25% P through inorganic + 75% through FYM, 25% P through inorganic + 75% through VC, 25% P through inorganic + 75% through PM) and two treatments of microbial inoculation (uninoculated and seed inoculation with PSB). Results revealed that among phosphorus management treatments, application of 50% P through inorganic + 50% through VC significantly increased the growth characters and yield of groundnut *viz.*, crop dry matter accumulation at most of the stages, number and weight of root nodules plant^{-1}, CGR and chlorophyll content over rest of the treatments. It also recorded the significantly highest pod yield (2198 kg ha^{-1}), haulm yield (3009 kg ha^{-1}) and biological yield (5207 kg ha^{-1}) of groundnut. However, it showed statistical equivalence with 50% P through inorganic + 50% through PM in most of the growth and yield of the crop. Results further indicated that inoculation of groundnut seed with PSB significantly enhanced the growth characters and yield over uninoculated control. Seed inoculation with PSB also improved to pod, haulm and biological yield of groundnut to the extent of 20.3, 12.4 and 15.7 per cent over control, respectively.

Tekulu *et al.* (2020) conducted a study to investigate the effects of nitrogen (N) and phosphorus (P) fertilizers on parameters of phenology, growth performance, grain yield, yield components, grain protein content of groundnut, and residual soil nitrogen content in the northern Ethiopia during the growing season of 2017. Three levels of N (0, 15 and 30 kg ha^{-1}) and four levels of P_2O_5 (0, 23, 46 and 69 kg ha^{-1}) were set in factorial combinations of randomized complete block design with three replications. Results showed that an average total biomass yield increased by 22.5% for separate individual application of 15 kg N ha^{-1} and by 16.6% for 46 kg P_2O_5 ha^{-1} compared to control plots. Haulm yield increased by 29.17% for plots treated with N fertilization compared to control plots. Average pod yield increased by 85.4% for a combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} fertilizers compared to the control plots. Plots fertilized with the highest combined rates of N and P have attained lower grain yield compared to the combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}. The highest grain protein contents were obtained for a combined application of 30 kg N ha^{-1} and zero P, and 15 kg N ha^{-1} plus 46 kg P_2O_5 ha^{-1}. The highest N harvest index was obtained for control treatments and for plots treated with combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}. Residual soil N content increased by 119% on plots with combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} compared to control plots. Based on results, combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} was recommended for increasing grain yield, grain protein content and residual soil nitrogen. The results of this study are crucial to improve groundnut productivity, grain protein content and also to provide implication on soil fertility management in a crop rotation system.

Vali *et al.* (2020) conducted a field experiment was in the crop research farm of SHUATS, Prayagraj to know the effect of phosphorus and zinc on growth and yield of summer groundnut. The experiment consisted of 12 treatments which includes three levels of phosphorus (30, 40 and 50 kg ha^{-1}) and four levels of zinc (0, 20, 25 and 30 kg ha^{-1}). The treatment receiving 50 kg phosphorus + 30 kg zinc ha^{-1} produced significantly higher plant height (35.58 cm), Pod yield (3.24 t ha^{-1}), total number of pods $plant^{-1}$ (29.56) and 100-kernel weight (39.35 g). However, net returns (139103.93 Rs. ha^{-1}) and B: C ratio (1.80) was also obtained maximum with the application of 50 kg phosphorus + 30 kg zinc ha^{-1}. This experiment shown treatment receiving 50 kg phosphorus + 30 kg zinc ha^{-1} were more productive and economic.

Hasan *et al.* (2019) conducted a pot experiment in ladang 15 at the Faculty of Agriculture; Universiti Putra Malaysia. The experiment was performed Randomized

Complete Block Design (RCBD). The size of the pot was 65.94 cm^2. The experiment was conducted in a factorial design with four levels of N (0, 10, 20, 30 kg ha^{-1}) and P (0, 20, 40 and 60 kg ha^{-1}). In this study, N and P fertilizer was played dominating role for vegetative growth of the plant. Plant height (20.65 cm), leaves number (262), leaf area (2140.54 cm^2), number of pods (47.25) and pod weight (22.8 g) increased with the application of level of N and P. Vegetative growth and yield of the plant was better at $N_{30}P_{60}$ kg ha^{-1} than the all other treatments. It can be concluded that by using $N_{30}P_{60}$ kg ha^{-1} growth and yield of bambara groundnut is maximum.

Mekdad (2019) conducted two field trials using four phosphorus fertilizer levels (P_1: 30, P_2: 45, P_3: 60 and P_4: 75 kg P_2O_5 fad^{-1}) and three foliar spray with boron levels (B_0: tap water, B_1: 100 ppm and B_2: 150 ppm) on peanut. Results indicated that yield components, yield and its quality of peanut were positively ($P \leq 0.01$) affected by the two factors individually, also had positively ($P \leq 0.05$) affected by the various interactions on pod yield. The best pod yield was obtained by the bilateral interaction application of $P_4 \times B_2$. Correlation analysis appeared appearance of highly significant with r values between oil and pod yields.

Mouri *et al.* (2018) carried out an experiment to evaluate the effect of variety and phosphorus on the yield and yield components of groundnut. The experiment comprising of two groundnut varieties *viz.*, BARI Cheenabadam-8 and BINA Cheenabadam-6 and four levels of phosphorus viz. 0, 20, 40 and 60 kg P ha^{-1}. The experiment was laid out in a randomized complete block design with three replications. The highest value of all the parameters e.g. leaf area index (2.02), dry matter (51.88 g $plant^{-1}$), number of primary branches $plant^{-1}$ (10.70), number of secondary branches $plant^{-1}$ (13.85), number of pegs $plant^{-1}$ (64.35), number of total pods $plant^{-1}$ (44.50), weight of 100 pods (94.66 g), weight of 100 seeds (44.47 g), shelling percentage (81.84%), seed yield (2.48 t ha^{-1}), pod yield (3.03 t ha^{-1}), stover yield (6.92 t ha^{-1}) and harvest index (30.45%) were recorded from BARI Cheenabadam-8 applied with 60 kg P ha^{-1}. The lowest value of all these parameters was found in BINA Cheenabadam-6 and with no applied phosphorus. So, it can be concluded that the variety BARI Cheenabadam-8 should preferably be fertilized with 60 kg P ha^{-1} to obtain the highest yield.

Kumar *et al.* (2014) conducted a field experiment at Main Agricultural Research Station (MARS), Dharwad to know the effect of nitrogen and phosphorus levels and ratios on yield and nutrient uptake by groundnut in northern transition zone of Karnataka. Groundnut cultivar JL 24 was tried during 2012 with eleven ratios of nitrogen (N) and phosphorus (P_2O_5) fertilizers with potassium level as constant (25 kg K_2O ha^{-1}). The yield attributing characteristics, dry pod yield and nutrient uptake were increased due to increasing N/P fertilizer ratios from 0.00 to 1.00. The treatment receiving N/P fertilizer ratio of 0.50 (30 kg N, 60 kg P_2O_5, 25 kg K_2O ha^{-1}) produced significantly higher dry pod yield (3310 kg ha^{-1}), number of filled pods plant^{-1} (17.47), total number of pods plant^{-1} (18.80) and 100-kernel weight (38.50 g). Further, the same treatment recorded significantly higher uptake (147.04 kg N, 23.30 kg P_2O_5, 118.48 kg K_2O, 10.93 kg S ha^{-1}) as compared to all other N/P fertilizer ratios. The treatment receiving N/P fertilizer ratio of 0.50 (30 kg N, 60 kg P_2O_5, 25 kg K_2O ha^{-1}) produced higher kernel yield (2441 kg ha^{-1}). However, it was on par with the treatment receiving N/P fertilizer ratio of 0.33 (2344 kg ha^{-1}).

Kabir *et al.* (2013) conducted a study to observe the effect of Phosphorus (P), Calcium (Ca) and Boron (B) on the growth and yield of groundnut cv. BARI Cheenabadam 7. Fertilizer doses of P (P_0= 0, P_1= 25 and P_2= 50 kg ha^{-1}), Ca (Ca_0= 0, Ca_1= 110 and Ca_2= 165 kg Ca ha^{-1}) and B (0, 2 and 2.5 kg ha^{-1}) were used. Among the growth parameters plant height, number of branches plant^{-1}, dry weight plant^{-1}, LAI and CGR were highest at 100 DAS in $P_2 \times Ca_1 \times B_2$ treatment combination. Among the yield attributing characters number of total pods plant^{-1} was highest for $P_1 \times Ca_2 \times B_2$, 100 pod weight plant^{-1} for $P_1 \times Ca_2 \times B_1$, shelling percentage, pod yield, biological yield, straw yield and harvest index for $P_2 \times Ca_1 \times B_2$. The lowest values of all these parameters were found at control treatment. The combined dose of P_2, Ca_1 and B_2 produced the highest values for almost all the above parameters. Thus, it can be concluded that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil.

Kamara *et al*. (2011) evaluated four groundnut varieties for their response to P fertilization in two Nigerian agro-ecological zones (sudan and northern Guinea savanna) during 2005 and 2006. The treatments included 0, 20, and 40 kg P ha^{-1} and groundnut varieties (Samnut 22, local Wadabura, Samnut 21 and Samnut 23).The results showed significant response of grain yield and yield components to P application confirming the importance of P for groundnut production in the Nigerian savannas. Pod yield increased linearly with increasing P rates in both years. Mean pod yield was higher by 49.3% at 20 kg and by 57.8% at 40 kg P ha^{-1} compared with unfertilized plots with Samnut 23 having more grain yield than other varieties at both locations in 2005.

Shiyam (2009) carried out an experiment on at the Crop Science Research Farm of the University of Calabar in the humid area of southeastern Nigeria, during the growing seasons of 2007 and 2008 to evaluate the optimum planting density and phosphorus requirement of a local groundnut (*Arachis hypogaea* L.) cultivar, 'Graffi'. The experiment was carried out five phosphorous rates 90, 20, 30, 40 and 50 kg P_2O_5 ha^{-1}) were applied to five plant densities of groundnut (47619, 57128, 71428, 95238 and 142857 plants ha^{-1}) laid out in a RCB design in three replications. Parameters assessed were plant height, branches plant, dry biomass yield ha^{-1}, filled pods $plant^{-1}$ and seed yield ha^{-1}. Results showed significant (P=0.05) effect of planting density on plant height, while phosphorus rates influenced the number of filled pods $plant^{-1}$ and seed yield ha^{-1}. Tallest plants with mean height of 53.2 cm were in plots containing 142,853 plants ha^{-1}, while the highest mean number of 15.2 filled pods $plant^{-1}$ and correspondingly highest mean seed yield of 1078.3 kg ha^{-1} were obtained by applying 40 kg P_2O_5 ha^{-1} to 95,238 plants ha^{-1}. It was concluded that planting the crop at 95,238 plants ha^{-1} with application of 40 kg P_2O_5 ha^{-1} would enhance optimum productivity of groundnut in the humid areas of southeastern Nigeria.

Hossain and Hamid (2007) carried out a field experiment to evaluate the effect of N and P application on the root growth, leaf photosynthesis and yield of groundnut (var. Basantibadam). Four levels of N (0, 20, 40 and 60 kg N ha^{-1}) and four levels of P (0, 13, 26 and 39 kg P ha^{-1}) were the treatment variables. The trial was set up in a randomized complete block design under factorial arrangement with three replications. Application of N and P fertilizer exerted significant effects on root development, photosynthesis, yield contributing characters and pod yield of the crop. Plant receiving 60 kg N and 39 kg P ha^{-1} had larger root system, greater photosynthetic rate and better yield contributing characters that resulted in the maximum pod yield which, however, was not significantly different from $N_{60}P_{26}$ treatment. Hence, it is recommended that higher yield of Basantibadam can be obtained from $N_{60}P_{26}$ kg ha^{-1} in salna silty clay loam soil of Madhupur tract (AEZ-28) of Bangladesh.

Gobarah *et al.* (2006) conducted two field trials during the two successive summer seasons of 2002 and 2003 in South AL-Tahrir sector, AL-Behaira Governorate, Egypt to study the effect of phosphorus fertilizer rates (30 and 60 kg P_2O_5 fad^{-1} and foliar spraying with zinc (tap water (control), 0.50, 0.75 and 1.00 g L^{-1}) on growth, yield and its components as well as seed quality of groundnut (Giza 6 cv.) grown in newly reclaimed sandy soil. The results showed that increasing rate of phosphorus fertilizer from 30 to 60 kg P_2O_5 fad^{-1} significantly increased vegetative growth, yield and its components as well as seed quality i.e. protein content and NPK percentages, while oil percentage did not reach to the level of significant by increasing the P rate. Foliar spraying with zinc levels had a significant effect on groundnut growth, yield and its components as well as seed quality. It was observed that the most of the characters under study increased significantly by the interaction between phosphorus fertilizer and foliar spraying with zinc expect dry weight of stem, P and oil percentages. It could be concluded that the highest yields of seed, oil and protein (1408, 633 and 368 kg fad^{-1}), respectively were obtained by application of 60 kg P_2O_5 fad^{-1} with foliar spraying with 1.00 g L^{-1} zinc.

2.2 Effect of calcium on groundnut

Ramya *et al.* (2022) conducted a field experimental trial was undertaken during the Kharif season of 2021 at crop research farm (CRF), Department of Agronomy, SHUATS Prayagraj (U.P.) to investigate the effect of gypsum and boron on yield and economics of groundnut. The treatments comprised of three gypsum levels *viz.*, 200 kg ha^{-1}, 300 kg ha^{-1}, 400 kg ha^{-1} and three boron levels *viz.*, 5 kg ha^{-1}, 10 kg ha^{-1}, 15 kg ha^{-1} which had an influence on groundnut. The experiment was consisted of nine treatments and three replications and was set up in a Randomized Block Design. The study revealed that the treatment with 400 kg ha^{-1} gypsum + 10 kg ha^{-1} boron was recorded significantly higher number of pods (31.36), seed yield (2674.17 kg/ha), haulm yield (3345.13 kg ha^{-1}) and harvest index (44.43%) compared to all other treatment combinations. The economic analysis demonstrates that 400 kg ha^{-1} gypsum + 10 kg ha^{-1} boron treatment produced higher gross returns (INR 149641.52 ha^{-1}), net returns (INR 101010.90 ha^{-1}) and B: C (2.07) ratio than all other treatment combinations. The challenges experienced throughout the research work were mostly related to the use of gypsum and boron, gypsum significantly raises all the parameters and use of boron improves nodulation of the plant. The application of 400 kg ha^{-1} gypsum increased the yield contributing features.

Hamza *et al.* (2021) conducted two experiments aimed at comparing conventional Ca and nano-Ca form effects on peanut production and quality traits. Abiotic stresses in sandy soil, which include saline water, saline soil, and lack of nutrients, affect the productivity and quality traits of peanuts (*Arachis hypogaea* L). Elemental calcium (Ca^{2+}) is necessary for the proper development of peanut pods. Treatments were control, gypsum plus calcium nitrate $Ca(NO_3)_2$, $Ca(NO_3)_2$, and chelated calcium, as well as 100%, 75%, 50%, 25%, and 12.5% of $Ca(NO_3)_2$ doses in a nano form. The results indicated that the treatment of gypsum plus conventional $CaNO_3$ achieved the highest yield and best quality traits, followed by the $Ca(NO_3)_2$ and 100% nano $Ca(NO_3)_2$ treatments. The treatments of the control, gypsum, and 12.5% nano $Ca(NO_3)_2$ had the lowest effect on peanut performance. The conventional treatment of gypsum plus $Ca(NO_3)_2$ resulted in the greatest seed yield (1.6 ton ha^{-1}), oil yield (700.3 kg ha^{-1}), and protein yield (380.1 kg ha^{-1}). Peanuts may benefit from Ca^{2+} better by using gypsum as the soil application and calcium nitrate as the foliar application to prevent disorders of Ca^{2+} deficiency under sandy soil conditions.

Rajanarasimha *et al.* (2021) conducted a field experiment during *Zaid* season of 2020-21 at crop research farm of SHUATS, Prayagraj to study about the influence of different methods of sulphur and calcium on growth and yield of groundnut. The experiment was laid out in most commonly encountered Randomized Block Design (RBD) with three replication of each treatment for all traits. In view of this experiment two methods are applied sulphur and calcium. Sulphur levels *viz.*, S_1 (15 kg ha^{-1}), S_2 (30 kg ha^{-1}) and S_3 (45 kg ha^{-1}); Calcium levels *viz.*, C_1 (20 kg ha^{-1}), C_2 (40 kg ha^{-1}), C_3 (60 kg ha^{-1}). Results were revealed that maximum plant height (73.56 cm), dry weight (32.06 g $plant^{-1}$), effective nodules $plant^{-1}$ (19.46), no of pods $plant^{-1}$ (21.33), no. of kernels pod^{-1} (2), seed index (42.80 g) were found to be significantly higher with application of treatment sulphur 45 kg ha^{-1} + calcium 60 kg ha^{-1} as compared to the other treatments. Maximum values were recorded higher in the application of sulphur 45 kg ha^{-1} + calcium 60 kg ha^{-1} in plant height (73.56 cm), kernel yield (2.17 t ha^{-1}), haulm yield (5.60 t ha^{-1}) and harvest index (36.40%).

Therefore, It can be concluded that the sulphur 45 kg ha^{-1} + calcium 60 kg ha^{-1} can produce more no. of pods plant^{-1} and kernels pod^{-1} and will be economically effective.

Vidya-Sagar *et al.* (2020) conducted an experiment to evaluate the effect of phosphorus and gypsum on growth, yield and economics of groundnut (*Arachis hypogaea* L.). The experiments comprising of 9 treatments, *viz.*, phosphorus levels at 40, 50 and 60 kg ha^{-1} along with 3 levels of gypsum at 200, 300 and 400 kg ha^{-1}. It was laid out in a Randomized Block Design and replicated thrice. Maximum plant dry weight was recorded with phosphorus 60 kg ha^{-1} along with gypsum 400 kg ha^{-1}. Yield attributes namely more number of pods plant^{-1} and kernel yield was recorded with phosphorus at 60 kg ha^{-1} along with gypsum at 300 kg ha^{-1}. Net returns and benefit cost ratio (BCR) was also recorded in the aforesaid treatment.

Patro and Ray (2016) conducted a field experiment was at Breeder Seed Production Farm of Orissa University of Agriculture and Technology, Bhubaneswar for three consecutive Kharif seasons of 2010, 2011 and 2012 in factorial complete randomized block design with 8 treatments replicated three times. The treatments consisted of four rates of gypsum i.e. 200, 400, 600 and 800 kg ha^{-1} and two time application of gypsum i.e. 100% at sowing and 50% at sowing + 50% at 30 DAS. Results from the experiment revealed that, pod yield (1467 kg ha^{-1}) and haulm yield (2261 kg ha^{-1}) increased significantly with the increasing levels of gypsum up to 600 kg ha^{-1}, which was at par with gypsum @ 800 kg ha^{-1}. The increase in pod yield due to application of gypsum @ 600 kg ha^{-1} was 34.5% more over gypsum @ 200 kg ha^{-1}. Highest dry pod weight plant^{-1} (63.3 g), number of pods plant^{-1} (18.2), shelling per cent (69.2) was recorded with the application of gypsum @ 800 kg ha^{-1} which was at par with 600 kg ha^{-1}. Nitrogen, sulphur and calcium uptake in pod and haulm of groundnut increased significantly with increasing levels of gypsum up to 600 kg ha^{-1}. Similar trend was observed for gross return (Rs. 37617 ha^{-1}), net return (Rs. 18326 ha^{-1}) and B:C ratio (2.09) of groundnut with application of gypsum @ 600 kg ha^{-1}. Split applications of gypsum significantly improved pod yield, haulm yield, kernel yield and yield attributes as well as economics of groundnut over basal application of entire dose of gypsum. However interaction effect was found to be non-significant.

Yadav *et al.* (2015) studied the effect of gypsum on growth and yield of groundnut (*Arachis hypogaea* L.) and found that highest fresh weight of pod was recorded under treatment T_2 (NPK=25:50:20 kg ha^{-1} + gypsum @ 200 kg ha^{-1}) (37.88 q ha^{-1}) and minimum with treatment T_0 (no fertilizer and gypsum) (9.35 q ha^{-1}). They also reported that maximum yield was recorded with treatment T_2 (NPK=25:50:20 kg ha^{-1} + gypsum @ 200 kg ha^{-1}) (26.10 q ha^{-1}) followed by T_4 (NPK=25:50:20 kg ha^{-1} + gypsum @ 400 kg ha^{-1}) (18.15 q ha^{-1}) and T_3 (NPK=25:50:20 kg ha^{-1} + gypsum @ 300 kg ha^{-1}) (17.05 q ha^{-1}) and T_1 (NPK=25:50:20 kg ha^{-1} + gypsum @ 100 kg ha^{-1}) (13.40 q ha^{-1}). Minimum yield was recorded with treatment T_0 (no fertilizer and gypsum) (7.55 q ha^{-1}).

Thilakarathna *et al*. (2014) conducted an experiment to investigate the influence of gypsum application on yield and visual quality of groundnut (*Arachis hypogaea* L.) grown in maspotha in kurunegala district of Sri Lanka was and observed that treatment T_4 (250 kg ha^{-1} of gypsum) showed the highest (1297.67 g) fresh weight $plot^{-1}$ and the lowest (937.67 g) fresh weight $plot^{-1}$ gave the control (0 kg ha^{-1} of gypsum). They also reported that treatment T_4 (250 kg ha^{-1} of gypsum) showed the highest (865.11 g) dry weight $plot^{-1}$ and the lowest (618.00 g) dry weight $plot^{-1}$ gave the control (0 kg ha^{-1} of gypsum).

Kabir *et al.* (2013) conducted a study to observe the effect of Phosphorus (P), Calcium (Ca) and Boron (B) on the growth and yield of groundnut cv. BARI Cheenabadam 7. Fertilizer doses of P (P_0= 0, P_1= 25 and P_2= 50 kg ha^{-1}), Ca (Ca_0= 0, Ca_1= 110 and Ca_2= 165 kg Ca ha^{-1}) and B (0, 2 and 2.5 kg ha^{-1}) were used. Among the growth parameters plant height, number of branches $plant^{-1}$, dry weight $plant^{-1}$, LAI and CGR were highest at 100 DAS in $P_2 \times Ca_1 \times B_2$ treatment combination. Among the yield attributing characters number of total pods $plant^{-1}$ was highest for $P_1 \times Ca_2 \times B_2$, 100 pod weight $plant^{-1}$ for $P_1 \times Ca_2 \times B_1$, shelling percentage, pod yield, biological yield, straw yield and harvest index for $P_2 \times Ca_1 \times B_2$. The lowest values of all these parameters were found at control treatment. The combined dose of P_2, Ca_1 and B_2 produced the highest values for almost all the above parameters. Thus, it can be concluded that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil.

Bagarama *et al*. (2012) studied the effect of gypsum and NPK fertilizer on groundnut performance in Western Tanzania and reported that the application of gypsum material and NPK significantly reduced the number of unfilled groundnut pods compared to the control treatment. The lowest number of unfilled pods 25 plants^{-1} (93) was found in treatment T_4 (groundnut + 400 kg ha^{-1} gypsum) soil mineral, while the control treatment T_1 (sole groundnuts) had the highest number unfilled pods 25 plants^{-1} (202).

Kamara *et al*. (2011) conducted an experiment to find out the effect of calcium and phosphorus fertilizer on the growth and yield of groundnut (*Arachis hypogaea* L.). They reported that calcium application significantly influenced pod yields. Application of 100 kg Ca ha^{-1} resulted in highest (3076 kg ha^{-1}) pod yield whereas control gives the lowest one.

Rahman (2006) investigated the effect of calcium and *Bradyrhizobium* inoculation of the growth, yield and quality of groundnut (*A. hypogaea* L.) and reported that calcium had a positive effect on the mature pods plant^{-1} and affected significantly in 1997-98 and 1998-99. The highest mature pods plant^{-1} was obtained in the treatment of 150 kg Ca ha^{-1} in 1997-98 and the other treatments varied significantly. In 1998-99, the highest mature pods plant^{-1} was obtained in the treatment of 150 kg Ca ha^{-1} that produced identical number with treatment 100 kg Ca ha^{-1} and 200 kg Ca ha^{-1}. The lowest number pods plant^{-1} was obtained in the treatment of 0 kg Ca ha^{-1}. He also reported that the mature pods plant^{-1} interacted significantly by calcium and *Bradyrhizobium* in 1997-98 only. In 1997-98, the highest mature pods plant^{-1} was produced with 100 kg Ca ha^{-1} with inoculation and the lowest matured pods plant^{-1} was produced in control.

Rao and Shaktawat (2001) conducted a field experiment during 1997-99 to study the effect of organic manure, phosphorus and gypsum on growth, yield and quality of ground nut under rainfed conditions. Application of organic manure significantly increased number of branches, leaf area index, root dry weight, hydration ratio and periodic dry matter accumulation (DMA) and thereby yield and quality of ground nut. A mean increase of 14.0 and 11.3% in pod yield was recorded under FYM and poultry manure applications over control (16.22 q ha^{-1}). Results revealed that application of 60 kg P_2O_5 ha^{-1} significantly increased growth, yield and quality parameters compared to 20 kg P_2O_5 ha^{-1}. The effect of gypsum either in single or in split doses on DMA at 45 DAS was not evident but as crop growth advanced, the effect on all growth parameters was evident. The two modes of gypsum application proved equally effective in increasing pod yield of groundnut. Gypsum treatments significantly increased harvest index of ground nut on pooled basis. Oil and protein content of groundnut kernel increased significantly under gypsum treatments. Germination percentage of groundnut kernel increased significantly under varied gypsum treatments.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka to determine the effect of phosphorus and calcium on the yield and seed quality of groundnut. Materials used and methodologies followed in the present investigation have been described in this chapter.

3.1 Experimental site

Geographically the experimental field was located at 23° 77' N latitude and 90° 33' E longitudes at an altitude of 8.2 m above the mean sea level (Anon, 1987). The soil belongs to the Agro-Ecological Zone “Modhupur Tract” (AEZ-28). The experimental site has been shown in the Map of AEZ of Bangladesh in Appendix- I.

3.2 Soil characteristics

The land topography was medium high and soil texture was silty clay with pH 5.6. The morphological, physical and chemical characteristics of the experimental soil have been presented in Appendix-II.

3.3 Climate and weather

The climate of the experimental site was under the subtropical climate with three distinct seasons: winter from November to February, pre-monsoon or hot season from March to April, and monsoon season from May to October (Edris *et al.*, 1979). The Bangladesh Meteorological Department, Agargoan, Dhaka, provided details of the meteorological data collected during the experiment, which are presented in Appendix III.

3.4 Crop/plating material

The groundnut variety, BARI cheenabadam-10 was considered as the test crop for the present study.

3.5 Experimental details

The experiment consisted of two factors *viz.*, phosphorus levels and calcium levels as mentioned below:

Factor A: Phosphorus levels (4)

P_1= 0 kg P ha^{-1} (Control)

P_2= 29 kg P ha^{-1} (145 kg TSP ha^{-1})

P_3= 32 kg P ha^{-1} (160 kg TSP ha^{-1})

P_4= 35 kg P ha^{-1} (175 kg TSP ha^{-1})

Factor B: Calcium levels (4)

Ca_1= 0 kg Ca ha^{-1} (Control)

Ca_2= 55 kg Ca ha^{-1} (275 kg gypsum ha^{-1})

Ca_3= 60 kg Ca ha^{-1} (300 kg gypsum ha^{-1})

Ca_4= 65 kg Ca ha^{-1} (325 kg gypsum ha^{-1})

A total of 16 treatment combinations:

P_1Ca_1	P_1Ca_2	P_1Ca_3	P_1Ca_4
P_2Ca_1	P_2Ca_2	P_2Ca_3	P_2Ca_4
P_3Ca_1	P_3Ca_2	P_3Ca_3	P_3Ca_4
P_4Ca_1	P_4Ca_2	P_4Ca_3	P_4Ca_4

3.6 Experimental design and layout

The experiment was laid out in a split-plot design with three replications where phosphorus fertilizers were considered in the main plot and calcium fertilizers application in sub plot. Four levels of phosphorus fertilizer and four calcium fertilizer applications gave altogether 16 treatment combinations of the experiment. The area of the experimental plot was divided into three equal blocks. Each block was divided into 4 equal main plots and the main plots were further divided into 4 sub-plots. The size of each unit plot was 2.00 m × 2.00 m. Distances between replications and plots were 0.75 m and 0.5 m, respectively. The layout of the experimental field is presented in Appendix IV.

3.7 Seed collection

The seed of groundnut variety BARI cheenabadam-10 was collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, Bangladesh.

3.8 Description of the variety

BARI cheenabadam-10 is a high yielding variety of groundnut developed by Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh. The variety was released in the year of 2016. The main characteristics is that- plant is erect type, plant height is about 40-45 cm, number of pods plant^{-1} is between 22 to 25, cluster pod bearing, surface of the pod not smooth and vain prominent, seeds brown in color and medium in size, 100-seed weight is about 45 g. Crop duration in Rabi season is about 140-155 days and in kharif season is about 120-135 days. Oil content is about 48-50%. This variety is tolerant to drought and diseases. Planting season and time of this variety is cultivated throughout the country in rabi and kharif season, sowing time in rabi season Mid October to Mid-November and kharif season July to August. Yield of this variety is about 2.0-2.5 t ha^{-1}.

3.9 Land preparation

The plot chosen for the experiment was opened with a power tiller in the last week of March, 2021 and was exposed to the sun for a few days before being harrowed, ploughed, and cross-ploughed several times, followed by laddering to achieve a good tilth. Weeds and stubble were removed, resulting in a soil tilth suitable for seed sowing. The land preparation was finished on April 2, 2021. Individual plots were created by creating ridges (20 cm high) around each plot to limit lateral irrigation water runoff.

3.10 Fertilizers application

Application of fertilization (basal dose) was completed on 3rd April, 2021. Fertilizers were applied to the experimental plot considering the recommended doses of BARI (2019).

Fertilizers	Doses ha^{-1}
Urea	25 kg
TSP	As per treatment
MoP	85 kg
Gypsum	As per treatment
$ZnSO_4$	4 kg
Boric acid	10 kg

Half of urea along with other fertilizers were applied during final land preparation as basal dose and thoroughly mixed with soil. The rest half urea was applied at 45 days after sowing (DAS) when flowers were initiated by side dressing. TSP and gypsum were applied during the final land preparation as basal dose as per treatment and thoroughly mixed with the soil.

3.11 Seed sowing

Seeds of the variety of groundnut (BARI cheenabadam-10) were sown at the rate of 100 kg ha^{-1} (unshelled groundnut) on 4^{th} April, 2021. The groundnuts were first unshelled and treated with Bavistin 250 WP @ 2 g kg^{-1} seed, then sown in lines maintaining a line to line distance of 30 cm and seed to seed distance of 15 cm having 2 seeds $hole^{-1}$ in the well prepared plot.

3.12 Intercultural operations

After establishment of seedlings, various intercultural operations were accomplished for better growth and development of the groundnut.

3.12.1 Irrigation and drainage

Pre-sowing irrigation was given to ensure the maximum germination percentage. Generally for upland soil 2 irrigations are required but considering the experiment field soil condition several time irrigations was given. Irrigations were given depending on the soil moisture content after soil moisture testing by hand. Before harvesting a last irrigation was given for convenience harvesting.

3.12.2 Gap filling, thinning, weeding and mulching

Thinning and gap filling were done at 20 and 23 DAS, respectively to maintain the uniformity of plant population. The crop was infested with some weeds during the early stage of crop establishment. Two hand weedings were done. After irrigation the soil surface became crusty, so there needed several operations done manually to break down the hard soil crust.

3.12.3 Earthing up

Earthing up was done lightly on 40 days after sowing. It was done to encourage pegging and potential pod development.

3.12.4 Plant protection

Bavistin 250 WP was directly applied in the row to control ant. Insecticide Ripcord 10 EC @ 1 ml litre^{-1} water were mixed and then sprayed on the leaves two times by knapsack sprayer to control jute hairy caterpillar, jessed and cutworm to protect the crop. Autistin 50 WDG and Mancer 75WP were used as fungicide to control foot and root rot of groundnut.

3.13 Harvesting and post-harvest operation

There is a thumb rule that the crop should be harvested when about 75% of the pods became mature at 115 DAS. After observing some maturity indices such as leaf became yellow, spots on the leaf, pod became hard and tough and dark tannin discoloration inside the shell crops were harvested. The samples were collected from the area of 1 m^2 of each plot avoiding the border plants. During harvest the pod contained 35% moisture. The harvested crops were tied into bundles and carried to the threshing floor. Then the pods were separated from the plants. The separated pod and the stover were sun dried by spreading those on the threshing floor. The seeds were separated from the pod and dried in the sun for 3 to 5 consecutive days for achieving safe moisture (8%) of seed.

3.14 Data collection and recording

Experimental data were recorded from stipulated dates and continued until harvest. The followings data were recorded during the experimentation:

i. Plant height
ii. Number of leaves plant^{-1}
iii. Number of branches plant^{-1}
iv. Number of pods plant^{-1}
v. Pod length
vi. 100-seed weight
vii. Seed yield plot^{-1}
viii. Pod yield
ix. Seed yield
x. Stover yield
xi. Biological yield
xii. Harvest index

xiii. Protein content

xiv. Oil content

xv. Vitamin E content

xvi. Germination percentage

3.15 Procedure of recording data

3.15.1 Plant height

Five plants were selected randomly from the inner rows of each plot. The height of the plants was measured from the ground level to the tip of the plant at 25, 50, 75, 100 DAS and at harvest. The mean value of plant height was recorded in cm.

3.15.2 Number of leaves plant^{-1}

Five plants were selected randomly from the inner rows of each plot. Leaves plant^{-1} was counted from each plant sample and then averaged at 25, 50, 75, 100 DAS and at harvest.

3.15.3 Number of branches plant^{-1}

The branches plant^{-1} was counted from five randomly sampled plants. It was done by counting total number of branches of all sampled plants then the average data were recorded.

3.15.4 Number of pods plant^{-1}

The pods plant^{-1} was counted from five randomly sampled plants. It was done by counting total number of pods of all sampled plants then the average data were recorded.

3.15.5 Pod length

Pod length was recorded from randomly selected 10 pods of each plot and the average was taken and expressed in centimeter (cm).

3.15.6 Weight of 100-seed

From the seed stock of each plot 100 seeds were counted randomly and the weight was measured by an electrical balance. It was recorded in gram (g).

3.15.7 Seed yield plot^{-1}

Pod yield plot^{-1} was calculated from shelled, cleaned and well dried grains collected from each plot and expressed as gram (g) plot^{-1} at 8 % moisture basis.

3.15.8 Pod yield

Pod yield was calculated from unshelled, cleaned and well dried grains collected from the central 1 m^2 area of inner rows of each plot (leaving boarder rows) and expressed as t ha^{-1} at 8 % moisture basis.

3.15.9 Seed yield

Seed yield was calculated from shelled, cleaned and well dried grains collected from the central 1 m^2 area of inner rows of each plot (leaving boarder rows) and expressed as t ha^{-1} at 8 % moisture basis.

3.15.10 Stover yield

Stover yield was determined from the central 1 m^2 area of inner rows of the each plot. After threshing, the sub sample was oven dried to a constant weight and finally converted to t ha^{-1}.

3.15.11 Biological yield

It was the total yield including both the economic and stover yield as follows:

$$\text{Biological yield (t ha}^{-1}\text{)} = \text{Pod yield (t ha}^{-1}\text{)} + \text{Stover yield (t ha}^{-1}\text{)}$$

3.15.12 Harvest index

Harvest index is the ratio of economic (grain) yield and biological yield. It was calculated by dividing the grain yield from the harvested area by the biological yield of the same area and multiplying by 100.

$$\text{Harvest Index (\%)} = \frac{\text{Pod yield (t ha}^{-1}\text{)}}{\text{Biological yield (t ha}^{-1}\text{)}} \times 100$$

3.16 Quality parameters

Seed protein content, oil content and vitamin E content were analyzed at Bangladesh Council of Scientific and Industrial Research (BCSIR).

3.16.1 Protein content

The protein content was evaluated by the multiplication of total nitrogen with 6.25 (Kaishar *et al.*, 2010), which was determined by following the Micro-Kjeldahl's method (Devani *et al.*, 1989).

3.16.2 Oil content

Oil content was determined by the standard soxhlet extraction procedure using petroleum ether by Soxhlet apparatus (AOAC, 1990) which was used by Inuwa *et al.* (2011).

3.16.3 Vitamin E content

Ejoh and Ketiku (2013) used a procedure to analysis the vitamin E content of groundnut seed and in the present study we also followed the same procedure to determine the vitamin E content of groundnut seed.

3.16.4 Germination percentage

After harvesting pods were stored in a natural condition and seeds were taken for germination test. Then 25 seeds for each treatment were taken in each petridish to evaluate the percentage of seed germination. The number of germinated seeds was counted and finally germination percentage was recorded.

3.17 Statistical analysis

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program MSTAT-C and then mean difference were adjusted by Least Significance difference (LSD) test at 5% level of significance (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

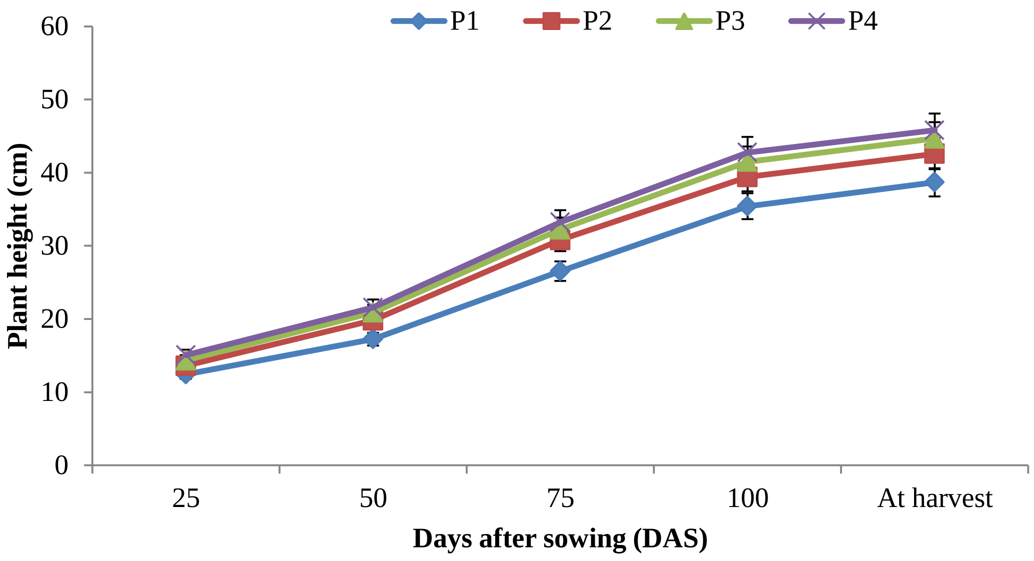
RESULTS AND DISCUSSION

The experiment was conducted to evaluate the effect of phosphorus and calcium fertilizer management on the growth, yield and seed quality of groundnut cv. BARI Cheenabadam-10. Data on different growth, yield contributing characters, yield and seed quality parameters of groundnut were recorded. The results have been presented and discussed with the help of graphs and tables and possible interpretations given under the following headings:

4.1 Plant height

4.1.1 Effect of phosphorus

Plant height rapidly increased from 25 DAS to 100 DAS and after that a slower rate of increase in plant height was recorded at harvest. Significant influence was found due to different levels of phosphorus fertilization (Figure 1). From the experimental result it revealed that plant height showed significant variation at 25, 50, 75, 100 DAS and at harvest due to phosphorus application. The maximum plant height (15.06, 21.57, 33.23, 42.76 and 45.79 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were recorded from P_4 treatment which was statistically similar with P_3 treatment at 25 and 75 DAS, respectively. On the other hand the minimum plant height (12.44, 17.25, 26.53, 35.41 and 38.69 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were recorded from P_1 treatment. The findings of the experiment was in coincided with the findings of LincoIn *et al.* (2022) reported that application of $ZnSO_4$ 30 kg ha^{-1} + phosphorus 60 kg ha^{-1} significantly increased the plant height as compared to control treatment. Vali *et al.* (2020) reported that treatment receiving 50 kg phosphorus + 30 kg zinc ha^{-1} produced significantly higher plant height. Hasan *et al.* (2019) reported that vegetative growth and yield of the plant was better at $N_{30}P_{60}$ kg ha^{-1}.

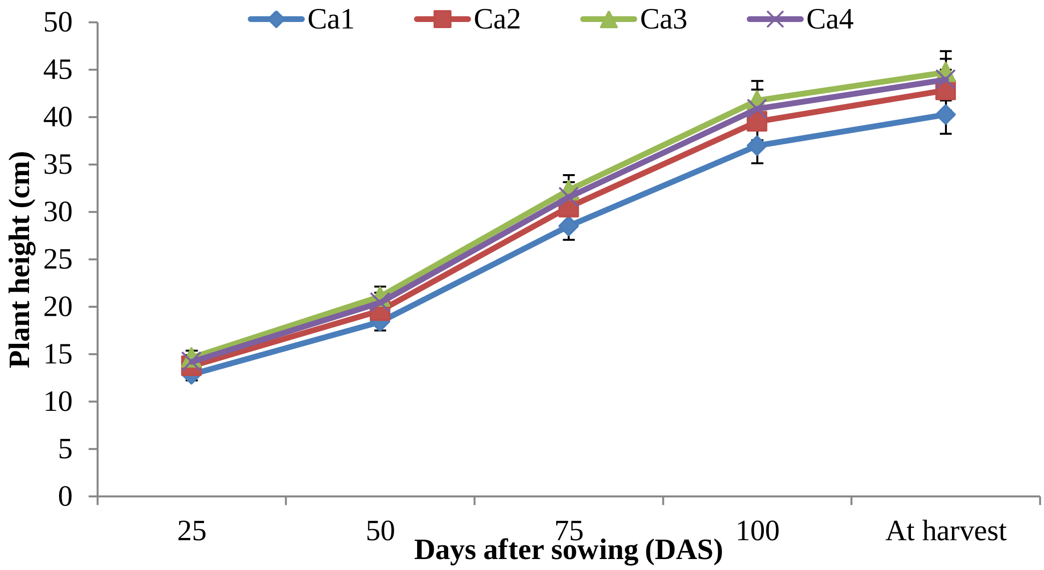


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 1. Effect of phosphorus on plant height at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.84, 0.34, 1.03, 1.25 and 0.70 at 25, 50, 75, 100 DAS and at harvest, respectively; vertical bars represent LSD value).

4.1.2 Effect of calcium

Statistically significant variation on plant height of groundnut at different growth stages were observed due to different application of calcium under the study (Figure 2). Results from the experiment revealed that the maximum plant height (14.63, 21.07, 32.27, 41.73 and 44.72 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were recorded from Ca_3 treatment which was statistically similar with Ca_4 treatment at 75 and 100 DAS, respectively. On the other hand the minimum plant height (12.86, 18.41, 28.49, 36.97 and 40.24 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Ca_1 treatment. Similar results were also observed by Rajanarasimha *et al.* (2021) revealed application of sulphur 45 kg ha^{-1} + calcium 60 kg ha^{-1} increases plant height significantly. Kabir *et al.* (2013) reported that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest plant height and yield of groundnut.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 2. Effect of calcium on plant height at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.28, 0.50, 0.72, 1.11 and 0.75 at 25, 50, 75, 100 DAS and at harvest, respectively; vertical bars represent LSD value).

4.1.3 Combined effect of phosphorus and calcium

Significant variation on plant height was observed due to combined effect of phosphorus and calcium (Table 1 and Appendix V). Results of the present study revealed that the maximum plant height (16.62, 23.33, 35.75, 45.81 and 48.33 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from P_4Ca_3 treatment combination which was statistically similar with P_4Ca_4 (22.46, 34.83, 44.67 and 47.52 cm at 50, 75, 100 DAS and at harvest, respectively) and P_3Ca_3 (43.75 cm at 100 DAS) treatment combinations. On the other hand the minimum plant height (12.19, 16.33, 25.39, 34.25 and 37.37 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were recorded from P_1Ca_1 treatment combinations which was statistically similar with P_1Ca_2 (12.41, 16.85, 26.14, 35.19 and 38.53 cm at 25, 50, 75, 100 DAS and at harvest, respectively); with P_1Ca_4 treatment combinations at 25 and 100 DAS and with P_1Ca_3 treatment combinations at 25 DAS and at harvest, respectively; with P_2Ca_1 and P_3Ca_1 treatment combinations at 25 DAS, respectively.

Table 1. Combined effect of phosphorus and calcium on plant height at different days after sowing (DAS) of groundnut

Treatment Combinations	Plant height (cm) at				
	25 DAS	50 DAS	75 DAS	100 DAS	Harvest
P_1Ca_1	12.19 h	16.33 l	25.39 l	34.25 l	37.37 k
P_1Ca_2	12.41 gh	16.85 kl	26.14 kl	35.19 kl	38.53 jk
P_1Ca_3	12.64 gh	18.13 ij	27.67 ij	36.41 i-l	39.87 ij
P_1Ca_4	12.50 gh	17.67 jk	26.93 jk	35.77 j-l	39.00 j
P_2Ca_1	12.82 gh	18.75 hi	28.82 hi	37.26 h-k	40.65 hi
P_2Ca_2	13.67 ef	19.67 f-h	30.81 e-g	39.37 f-h	42.61 fg
P_2Ca_3	14.05 d-f	20.66 d-f	32.00 de	40.93 d-f	43.85 ef
P_2Ca_4	13.81 d-f	20.19 e-g	31.55 d-f	40.11 e-g	43.27 ef
P_3Ca_1	13.11 f-h	19.17 h	29.64 gh	37.82 g-j	41.15 g-i
P_3Ca_2	14.37 de	20.76 de	32.73 cd	41.52 d-f	44.67 de
P_3Ca_3	15.19 bc	22.15 bc	33.67 bc	43.75 a-c	46.81 bc
P_3Ca_4	14.73 cd	21.48 cd	32.92 cd	42.85 b-d	46.00 cd
P_4Ca_1	13.33 fg	19.42 gh	30.11 f-h	38.56 g-i	41.77 gh
P_4Ca_2	14.55 c-e	21.07 de	32.24 c-e	42.00 c-e	45.55 cd
P_4Ca_3	16.62 a	23.33 a	35.75 a	45.81 a	48.33 a
P_4Ca_4	15.75 b	22.46 ab	34.83 ab	44.67 ab	47.52 ab
$LSD_{(0.05)}$	**0.56**	**1.00**	**1.45**	**2.22**	**1.50**
CV(%)	**2.43**	**3.00**	**2.81**	**3.33**	**2.08**

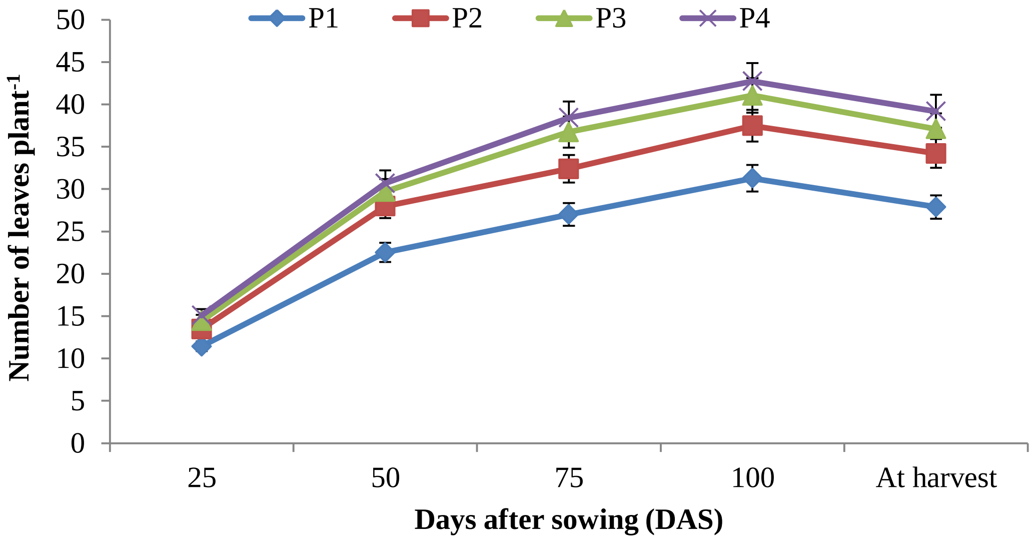
In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Here, P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}; Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

4.2 Number of leaves plant^{-1}

4.2.1 Effect of phosphorus

Total number of leaves plant^{-1} rapidly increased up to 100 DAS and then slowly decreased at harvest. Significant effect on number of leaves plant^{-1} at different days after sowing was found due to phosphorus fertilization under the present study (Figure 3). Result revealed from the study that the maximum number of leaves plant^{-1} (15.08, 30.69, 38.41, 42.73 and 39.18 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from P_4 treatment. On the other hand the minimum number of leaves plant^{-1} (11.44, 22.52, 27.00, 31.27 and 27.88 at 25, 50, 75, 100 DAS and at harvest, respectively) were observed in P_1 treatment. Similar result was also observed by Hasan *et al.* (2019) who reported that vegetative growth of the plant was better when plant treated with phosphorus and nitrogen fertilization than other treatments. Plant height, leaves number (262) and leaf area (2140.54 cm^2) increased with the application of level of N and P.

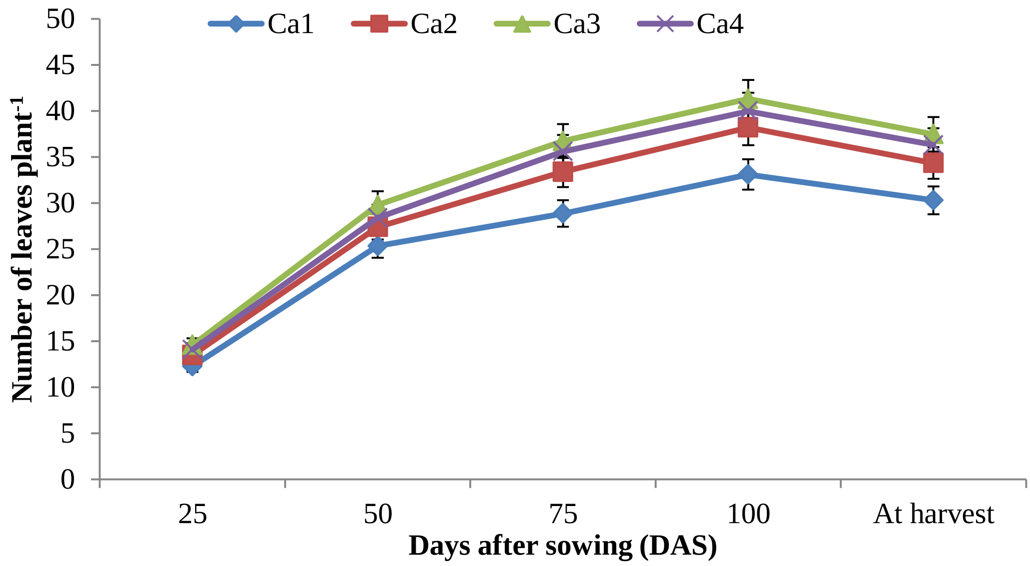


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 3. Effect of phosphorus on number of leaves plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.20, 0.82, 0.85, 1.35 and 0.48 at 25, 50, 75, 100 DAS and at harvest, respectively; vertical bars represent LSD value).

4.2.2 Effect of calcium

Significant effect showed on number of leaves plant^{-1} at different days after sowing due to application of calcium (Figure 4). From the experiment result revealed that the maximum number of leaves plant^{-1} (14.58, 29.77, 36.72, 41.29 and 37.46 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Ca_3 treatment. On the other hand the minimum number of leaves plant^{-1} (12.27, 25.32, 28.86, 33.09 and 30.29 at 25, 50, 75, 100 DAS and at harvest, respectively) was observed in Ca_1 treatment. The findings of study was in coincided with the findings of Vidya-Sagar *et al.* (2020) who reported that maximum plant growth related data was recorded with phosphorus 60 kg ha^{-1} along with gypsum 400 kg ha^{-1}.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 4. Effect of calcium on number of leaves plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.35, 0.64, 0.87, 0.86 and 0.63 at 25, 50, 75, 100 DAS and at harvest, respectively; vertical bars represent LSD value).

4.2.3 Combined effect of phosphorus and calcium

Combined effect of phosphorus and calcium revealed significant variation on number of leaves plant^{-1} of groundnut throughout the growing period (Table 2 and Appendix VI). Results from the experiment revealed that the maximum number of leaves plant^{-1} (16.50, 33.33, 42.81, 47.00 and 43.75 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from P_4Ca_3 treatment combinations which was statistically similar with P_4Ca_4 treatment combination at 25, 75 and 100 DAS, respectively. On the other hand the minimum number of leaves plant^{-1} (10.75, 20.81, 25.67, 29.81 and 26.75 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from P_1Ca_1 treatment combinations which was statistically similar with P_1Ca_2 treatment combination at 25, 50, 75, 100 DAS and at harvest, respectively; with P_1Ca_4 treatment combination at 75 DAS, respectively.

Table 2. Combined effect of phosphorus and calcium on number of leaves plant^{-1} at different days after sowing (DAS) of groundnut

Treatment Combinations	Number of leaves plant^{-1} at				
	25 DAS	**50 DAS**	**75 DAS**	**100 DAS**	**Harvest**
P_1Ca_1	10.75 l	20.81 k	25.67 k	29.81 j	26.75 k
P_1Ca_2	11.17 kl	21.67 jk	26.50 k	30.75 ij	27.42 jk
P_1Ca_3	12.15 ij	24.83 i	28.50 ij	32.67 h	29.00 i
P_1Ca_4	11.67 jk	22.75 j	27.33 jk	31.83 hi	28.33 ij
P_2Ca_1	12.42 i	26.33 h	29.33 hi	33.00 h	30.42 h
P_2Ca_2	13.50 fg	27.75 fg	31.75 g	37.50 ef	34.42 f
P_2Ca_3	14.17 ef	29.50 de	34.81 f	40.67 d	36.33 de
P_2Ca_4	13.83 f	28.33 ef	33.67 f	38.75 e	35.67 ef
P_3Ca_1	12.75 hi	26.81 gh	29.75 hi	33.81 gh	31.33 h
P_3Ca_2	14.50 de	29.81 d	36.75 e	41.83 d	37.00 d
P_3Ca_3	15.50 bc	31.42 bc	40.75 bc	44.81 b	40.75 b
P_3Ca_4	15.00 cd	30.75 b-d	39.67 cd	43.75 bc	39.33 c
P_4Ca_1	13.17 gh	27.33 f-h	30.67 gh	35.75 fg	32.67 g
P_4Ca_2	14.83 d	30.33 cd	38.50 d	42.67 cd	38.50 c
P_4Ca_3	16.50 a	33.33 a	42.81 a	47.00 a	43.75 a
P_4Ca_4	15.81 ab	31.75 b	41.67 ab	45.50 ab	41.81 b
$LSD_{(0.05)}$	**0.69**	**1.28**	**1.73**	**1.71**	**1.26**
CV(%)	**3.01**	**2.76**	**3.06**	**2.68**	**2.17**

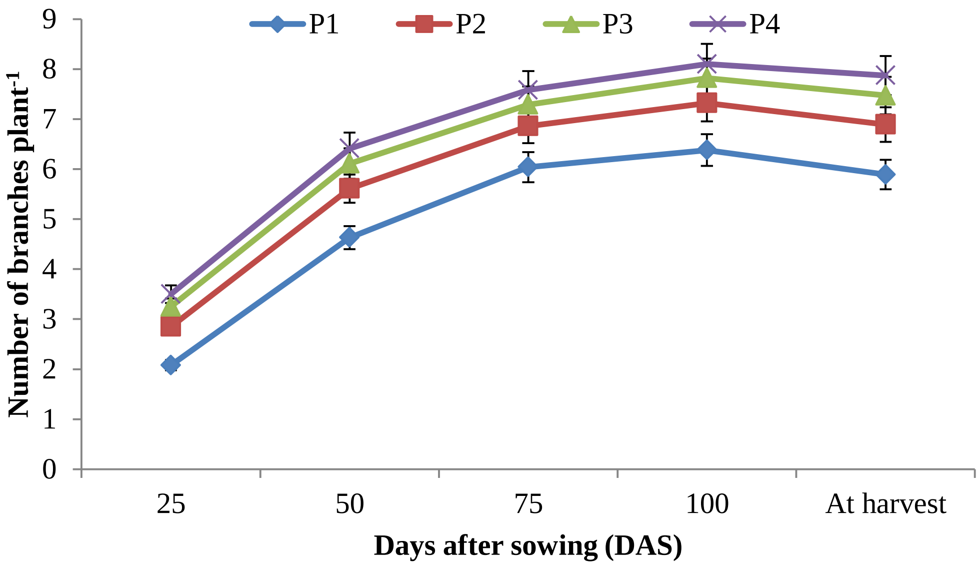
In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Here, P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}; Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

4.3 Number of branches plant^{-1}

4.3.1 Effect of phosphorus

A gradual increase of branches plant^{-1} was observed up to 100 DAS and after that a slower decreased was observed at harvest. Significant effect on number of branches plant^{-1} at different days after sowing was observed due to phosphorus fertilization under the present study (Figure 3). Maximum number of branches plant^{-1} (3.50, 6.41, 7.58, 8.10 and 7.87 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from P_4 treatment which was statistically similar with P_3 treatment at 75 DAS. On the other hand the minimum number of branches plant^{-1} of groundnut (2.08, 4.63, 6.04, 6.38 and 5.89 at 25, 50, 75, 100 DAS and at harvest, respectively) were observed in N_1 treatment. Similar trend also found by Mouri *et al.* (2018) who reported that application of 60 kg P ha^{-1} increases number of primary branches plant^{-1} (10.70), number of secondary branches plant^{-1} (13.85) of variety BARI Cheenabadam-8. Kabir *et al.* (2013) reported that growth parameters number of branches plant^{-1} was highest at 100 DAS in $P_2 \times Ca_1 \times B_2$ treatment combination.

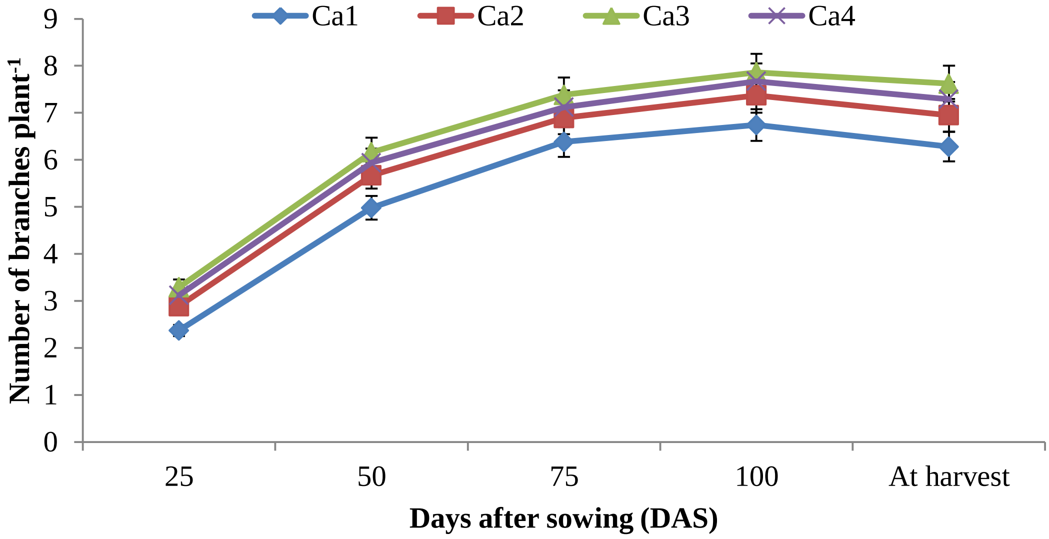


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 5. Effect of phosphorus on number of branches plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.16, 0.28, 0.30, 0.07 and 0.12 at 25, 50, 75, 100 DAS and at harvest, respectively; vertical bars represent LSD value).

4.3.2 Effect of calcium

Number of branches plant^{-1} showed significant variation at different days after sowing due to application of calcium (Figure 4). From the experiment result revealed that the maximum number of branches plant^{-1} groundnut (3.29, 6.16, 7.38, 7.86 and 7.62 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Ca_3 treatment whereas the minimum number of branches plant^{-1} of groundnut (2.37, 4.98, 6.38, 6.74 and 6.28 at 25, 50, 75, 100 DAS and at harvest, respectively) was observed in Ca_1 treatment. The result of the experiment was in coincided with the findings of Kamara *et al*. (2011) reported that calcium application significantly influenced number of branches plant^{-1}. Application of 100 kg Ca ha^{-1} resulted in maximum branches plant^{-1} whereas control gives the lowest one.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 6. Effect of calcium on number of branches plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.14, 0.16, 0.17, 0.08 and 0.13 at 25, 50, 75, 100 DAS and at harvest, respectively; vertical bars represent LSD value).

4.3.3 Combined effect of phosphorus and calcium

Combined effect of phosphorus and calcium application showed significant influence on number of branches plant^{-1} of groundnut under the study (Table 3 and Appendix VII). Results from the experiment revealed that the maximum number of branches plant^{-1} (4.00, 7.15, 8.33, 8.75 and 8.67 at 25, 50, 75, 100 DAS and at harvest, respectively) were achieved from P_4Ca_3 treatment combinations which was statistically similar with P_4Ca_4 treatment combination at 25 DAS, respectively. On the other hand the minimum number of branches plant^{-1} (1.82, 4.00, 5.67, 6.00 and 5.42 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 treatment combination at 25 and 75 DAS, respectively.

Table 3. Combined effect of phosphorus and calcium on number of branches plant^{-1} at different days after sowing (DAS) of groundnut

Treatment Combinations	Number of branches plant^{-1} at				
	25 DAS	**50 DAS**	**75 DAS**	**100 DAS**	**Harvest**
P_1Ca_1	1.82 l	4.00 l	5.67 j	6.00 l	5.42 i
P_1Ca_2	2.00 kl	4.67 k	6.00 ij	6.33 k	5.81 h
P_1Ca_3	2.33 ij	5.00 ij	6.33 hi	6.67 i	6.33 g
P_1Ca_4	2.15 jk	4.83 jk	6.15 i	6.50 j	6.00 h
P_2Ca_1	2.42 ij	5.17 h-j	6.42 hi	6.80 i	6.42 g
P_2Ca_2	2.81 g	5.67 e-g	6.83 fg	7.33 g	6.81 ef
P_2Ca_3	3.15 ef	5.83 e	7.17 d-f	7.67 e	7.33 d
P_2Ca_4	3.00 fg	5.75 ef	7.00 e-g	7.50 f	7.00 e
P_3Ca_1	2.50 hi	5.33 g-i	6.67 gh	7.00 h	6.50 g
P_3Ca_2	3.33 de	6.00 de	7.33 c-e	7.81 e	7.42 d
P_3Ca_3	3.67 bc	6.67 bc	7.67 bc	8.33 c	8.15 b
P_3Ca_4	3.50 cd	6.42 bc	7.50 b-d	8.15 d	7.81 c
P_4Ca_1	2.75 gh	5.42 f-h	6.75 f-h	7.15 h	6.75 f
P_4Ca_2	3.42 c-e	6.33 cd	7.42 c-e	8.00 d	7.75 c
P_4Ca_3	4.00 a	7.15 a	8.33 a	8.75 a	8.67 a
P_4Ca_4	3.82 ab	6.75 b	7.83 b	8.50 b	8.33 b
$LSD_{(0.05)}$	**0.28**	**0.32**	**0.35**	**0.16**	**0.25**
CV(%)	**5.82**	**3.42**	**3.00**	**1.29**	**2.11**

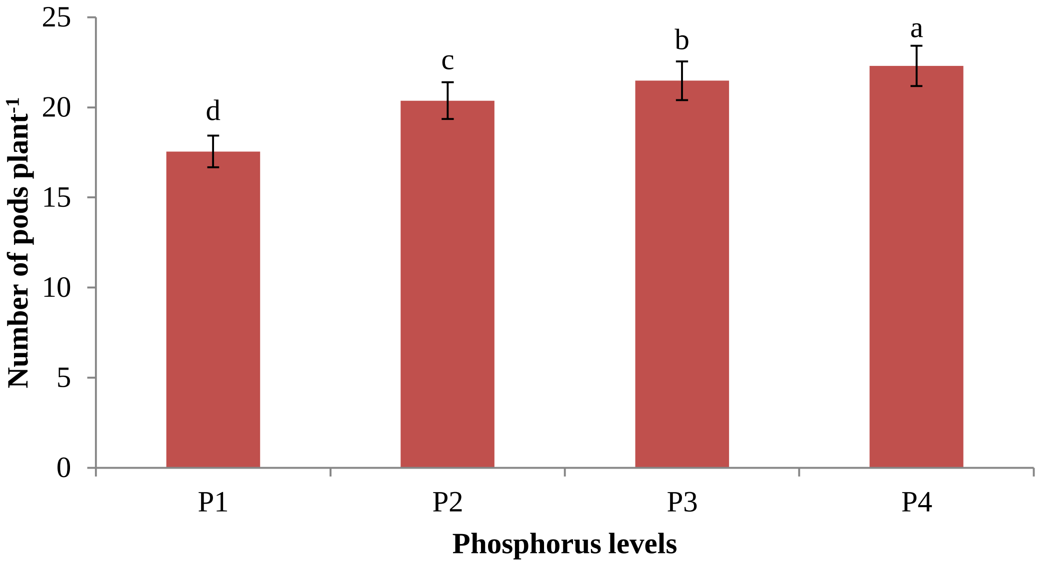
In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Here, P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}; Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

4.4 Number of pods plant^{-1}

4.4.1 Effect of phosphorus

Significant influence on number of pods plant^{-1} was observed due to the effect of phosphorus fertilization (Figure 7). Result from the experiment revealed that the maximum number of pods plant^{-1} (22.30) was obtained from P_4 treatment. On the other hand minimum number of pods plant^{-1} (17.55) was observed in P_1 treatment. The result of the experiment was in coincided with the findings of Lincoln *et al.* (2022) who reported that number of pods plant^{-1} (27.53) and number of kernels pod^{-1} (2) were recorded significantly higher with the application of $ZnSO_4$ 30 kg ha^{-1} + Phosphorus 60 kg ha^{-1} as compared to other treatments. Vali *et al.* (2020) reported that maximum number of pods plant^{-1} (29.56) obtained with the application of 50 kg phosphorus + 30 kg zinc ha^{-1}. Treatments receiving 50 kg phosphorus + 30 kg zinc ha-1 were more productive and economic.

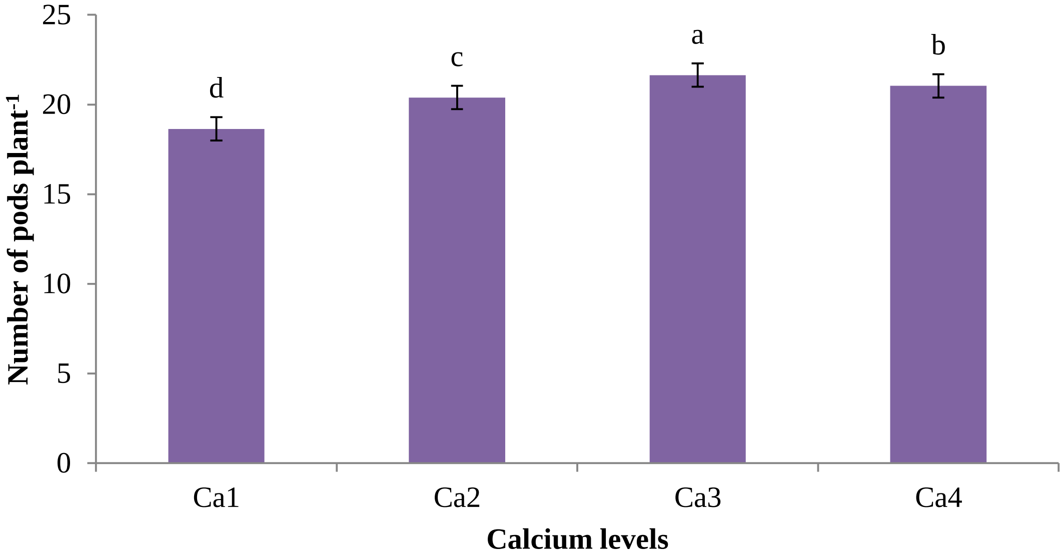


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 7. Effect of phosphorus on number of pods plant^{-1} of groundnut ($LSD_{0.05}$= 0.48; vertical bars represent LSD value).

4.4.2 Effect of calcium

Different application of calcium had significant effect on number of pods plant^{-1} of groundnut (Figure 8). Results from the experiment revealed that the maximum number of pods plant^{-1} (21.64) was achieved from Ca_3 treatment. On the other hand the minimum number of pods plant^{-1} (18.64) was obtained from Ca_1 treatment. Similar result was also observed by Kabir *et al.* (2013) reported that combined application of fertilizer P, Ca and B increased the yield contributing parameter number of pods plant^{-1} for obtaining the highest yield of groundnut. Rahman (2006) revealed that highest mature pods plant^{-1} was obtained in the treatment of 150 kg Ca ha^{-1} that produced identical number with treatment 100 kg Ca ha^{-1} and 200 kg Ca ha^{-1}. The lowest number pods plant^{-1} was obtained in the treatment of 0 kg Ca ha^{-1}.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 8. Effect of calcium on number of pods plant^{-1} of groundnut ($LSD_{0.05}$= 0.58; vertical bars represent LSD value).

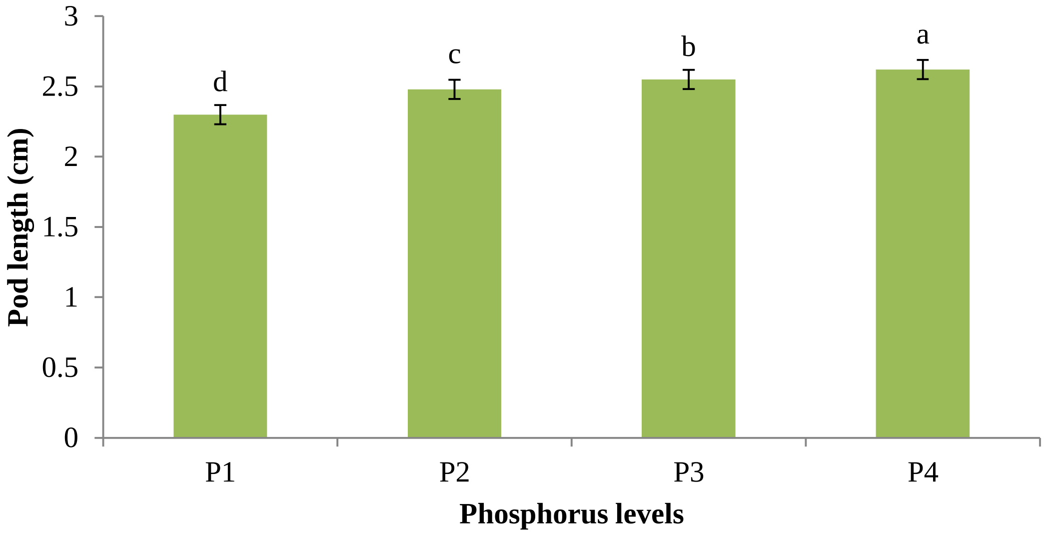
4.4.3 Combined effect of phosphorus and calcium

Significant difference was remarked for number of pods plant^{-1} of groundnut due to combined effect of phosphorus and calcium application (Table 4 and Appendix VIII). Results revealed that the maximum number of pods plant^{-1} (24.14) was observed in P_3Ca_3 treatment combination which was statistically similar with P_3Ca_4 (23.35) treatment combination. On the other hand the minimum number of pods plant^{-1} (16.65) was observed in P_1Ca_1 treatment combination which was statistically as par with P_1Ca_2, P_1Ca_4 and P_1Ca_3 treatment combinations.

4.5 Pod length

4.5.1 Effect of phosphorus

Pod length of groundnut revealed significant influence due to phosphorus under the present study (Figure 9). Results from the experiment revealed that the maximum pod length (2.62 cm) was obtained from P_4 treatment while the minimum pod length (2.30 cm) was recorded from P_1 treatment. Similar result was observed by Naabe *et al.* (2021) reported that cultivating groundnut by using P fertilizer and/or inoculant increases pod length and number of pods plant^{-1} for increasing groundnut yield. Vali *et al.* (2020) also reported that application of 50 kg phosphorus + 30 kg zinc ha^{-1} significantly increases pod length and number of pods plant^{-1} of groundnut.

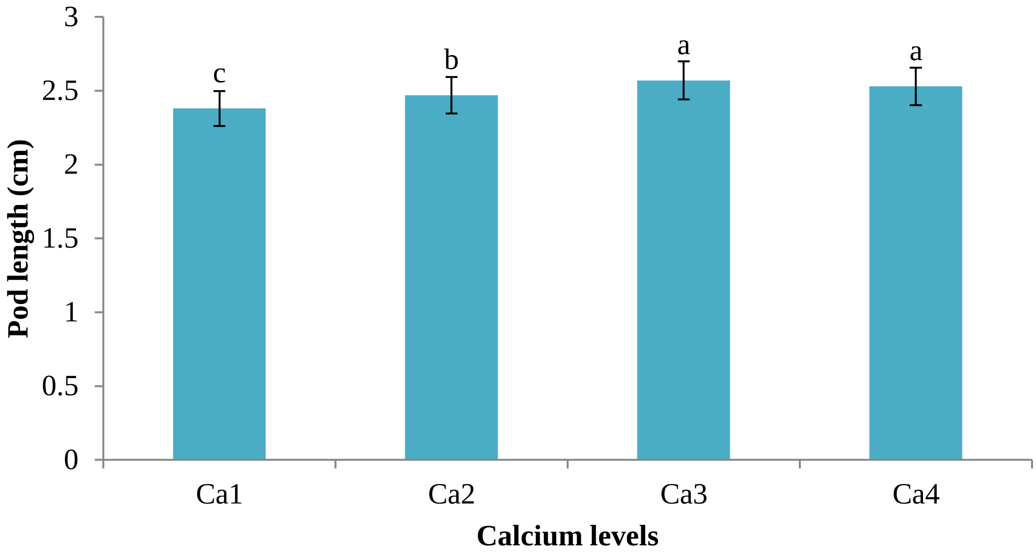


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 9. Effect of phosphorus on pod length of groundnut ($LSD_{0.05}$= 0.06; vertical bars represent LSD value).

4.5.2 Effect of calcium

Different levels of calcium application showed significant variation on pod length of groundnut under the experiment (Figure 10). Results from the experiment showed that the maximum pod length was observed in Ca_3 (2.57 cm) treatment which was statistically identical to Ca_4 (2.53 cm) treatment while the minimum pod length was obtained from Ca_1 (2.38 cm) treatment. The result of the study was in coincided with the findings of Rahman (2006) reported that the highest mature pods plant^{-1} and pod length were produced with 100 kg Ca ha^{-1} with inoculation and the lowest matured pods $plant^{-1}$ and pod length was produced in control.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 10. Effect of calcium on pod length of groundnut ($LSD_{0.05}$= 0.04).

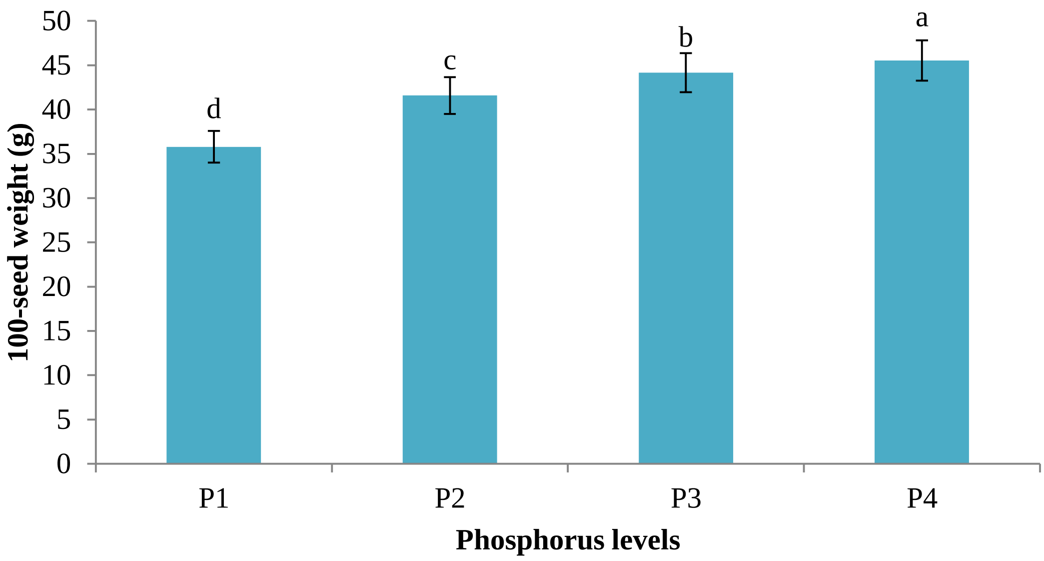
4.5.3 Combined effect of phosphorus and calcium

Combined effect of phosphorus and calcium application showed significant influence on pod length of groundnut (Table 4 and Appendix VIII). Result revealed that the maximum pod length (2.75 cm) was obtained from P_4Ca_3 treatment combination which was statistically similar with P_4Ca_4 (2.69 cm) treatment combination. On the other hand the minimum pod length of groundnut (2.24 cm) was obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 (2.28 cm) and P_1Ca_4 (2.31 cm) treatment combinations.

4.6 100 seeds weight

4.6.1 Effect of phosphorus

Effect of phosphorus revealed significant variation on 100 seeds weight of groundnut (Figure 11). Results from the experiment revealed that the maximum 100 seeds weight of groundnut (45.55 g) was obtained from P_4 treatment while the minimum 100 seeds weight of groundnut (35.78 g) was obtained from P_1 treatment. Similar trends was also observed by LincoIn *et al.* (2022) who reported that 100 seeds weight were increased with phosphorus fertilization on plant. Hasan *et al.* (2019) revealed that N and P fertilizer was played dominating role for vegetative growth of the plant. Plant height, leaves number, leaf area, number of pod and pod weight increased with the application of level of N and P. Vegetative growth and yield of the plant was better at $N_{30}P_{60}$ kg ha^{-1} than control treatment.

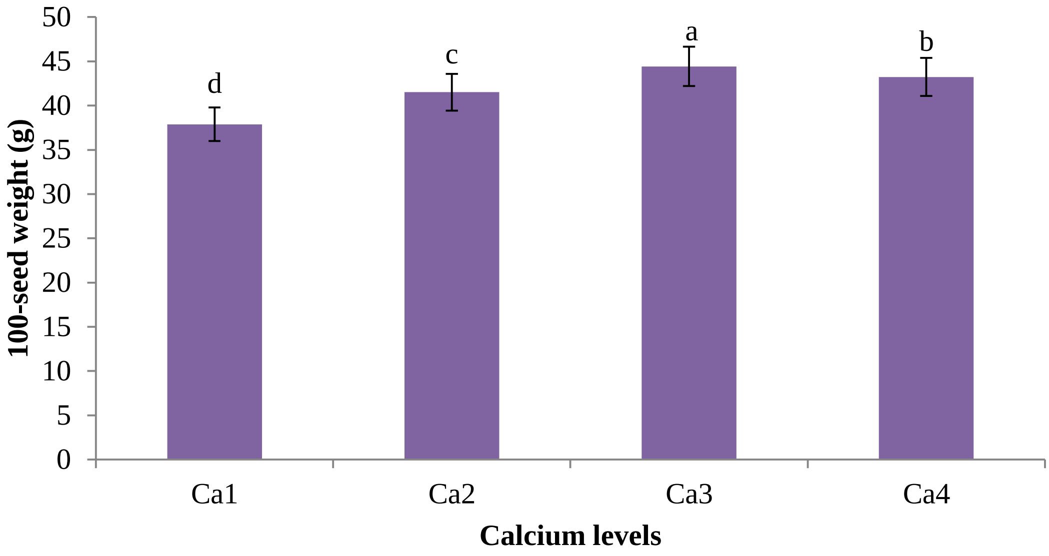


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 11. Effect of phosphorus on 100-seed weight of groundnut ($LSD_{0.05}$= 1.05; vertical bars represent LSD value).

4.6.2 Effect of calcium

100 seeds weight of groundnut showed significant variation due to different levels of calcium application (Figure 12). Result from the experiment showed that the maximum 100 seeds weight of groundnut (44.42 g) was obtained from Ca_3 treatment. On the other hand, the minimum 100 seeds weight of groundnut was obtained from Ca_1 (37.89 g) treatment. Mekdad (2019) revealed that among three foliar spray of boron levels (B_0: tap water, B_1: 100 ppm and B_2: 150 ppm) on peanut results indicated that yield components, yield and its quality of peanut were positively ($P \leq 0.01$) affected by the 150 ppm. Bagarama *et al*. (2012) reported application of gypsum material and NPK significantly reduced the number of unfilled groundnut pods compared to the control treatment.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 12. Effect of calcium on 100-seed weight of groundnut ($LSD_{0.05}$= 0.69; vertical bars represent LSD value).

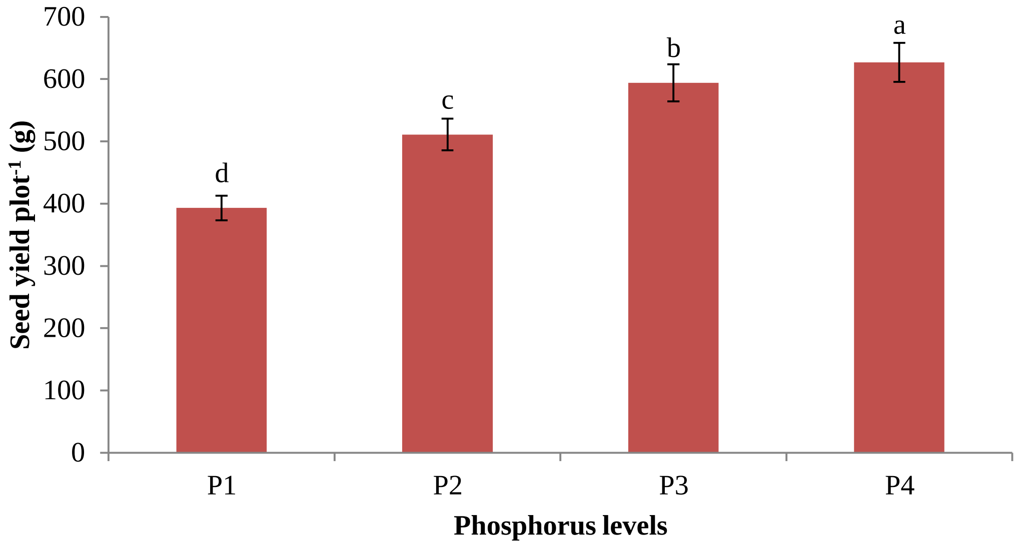
4.6.3 Combined effect of phosphorus and calcium

Combined effect of phosphorus and calcium showed significant variation on 100 seeds weight of groundnut under the present study (Table 4 Appendix VIII). Result revealed that the maximum 100 seeds weight of groundnut (49.33 g) was observed in P_4Ca_3 treatment combination. On the other hand the minimum 100 seeds weight of groundnut (33.18 g) was observed in P_1Ca_1 treatment combination.

4.7 Seed yield plot^{-1}

4.7.1 Effect of phosphorus

Different levels of phosphorus exerted significant variation on seed yield plot^{-1} of groundnut (Figure 13). The highest seed yield plot^{-1} of groundnut (627.00 g) was recorded from P_4 treatment whereas the lowest seed yield plot^{-1} of groundnut (393.00 g) was recorded from P_1 treatment. Similar result also found by Tekulu *et al.* (2020) who revealed that average pod yield increased by 85.4% for a combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} fertilizers compared to the control plots. Hasan *et al.* (2019) reported that vegetative growth and yield of the plant was better at $N_{30}P_{60}$ kg ha^{-1} than the all other treatments. It can be concluded that by using $N_{30}P_{60}$ kg ha^{-1} growth and yield of bambara groundnut is maximum.

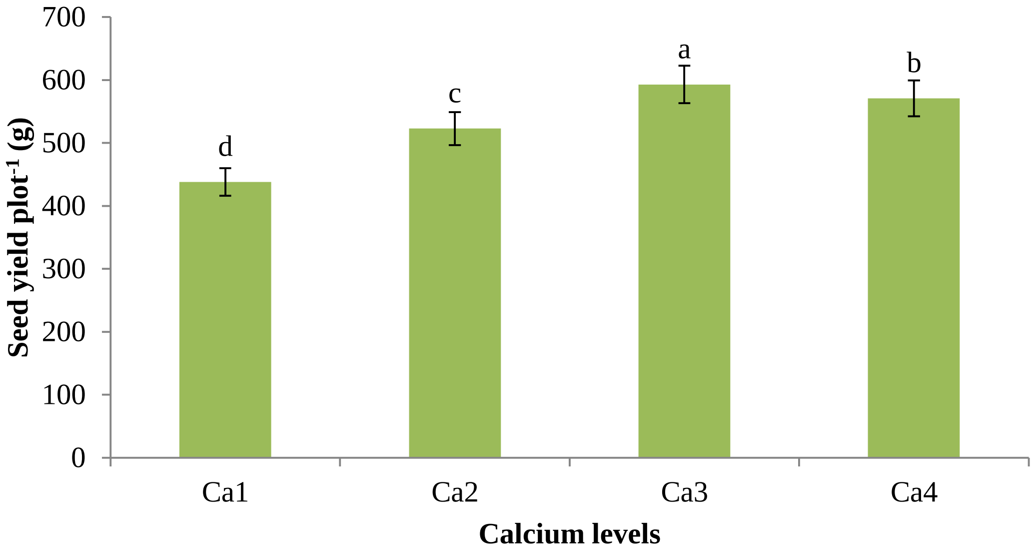


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 13. Effect of phosphorus on seed yield plot^{-1} of groundnut ($LSD_{0.05}$= 29.71; vertical bars represent LSD value).

4.7.2 Effect of calcium

Statistically significant influence was observed on seed yield plot^{-1} of groundnut persuaded by different levels of calcium application (Figure 14). The highest seed yield plot^{-1} of groundnut (593.00 g) was recorded from Ca_3 treatment. On the other hand the lowest seed yield plot^{-1} of groundnut (438.00 g) was recorded from Ca_1 treatment. The result of the experiment was coincided with the findings of Kabir *et al.* (2013) who reported that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil. Yadav *et al.* (2015) also reported that maximum yield was recorded with treatment T_2 (NPK + gypsum @ 200 kg ha^{-1}) (26.10 q ha^{-1}) followed by T_4, T_3 and T_1. Minimum yield was recorded with treatment T_0 (no fertilizer and gypsum) (7.55 q ha^{-1}).



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 14. Effect of calcium on seed yield plot^{-1} of groundnut ($LSD_{0.05}$= 20.11; vertical bars represent LSD value).

4.7.3 Combined effect of phosphorus and calcium

Seed yield plot^{-1} of groundnut affected significantly due to treatment combination of phosphorus and calcium (Table 4 and Appendix VIII). Results showed that the treatment combination of P_4Ca_3 gave the highest seed yield plot^{-1} (716.00 g) which was statistically followed by P_4Ca_4 and P_3Ca_3 treatment combinations whereas P_1Ca_1 gave the lowest seed yield plot^{-1} of groundnut (364.00 g) which was statistically similar with P_1Ca_2 and P_1Ca_4 treatment combinations.

Table 4. Combined effect of phosphorus and calcium on number of pods plant^{-1}, pod length, 100-seed weight and seed yield plot^{-1} of groundnut

Treatment Combinations	Number of pods plant^{-1}	Pod length (cm)	100-seed weight (g)	Seed yield plot^{-1} (g)
P_1Ca_1	16.65 l	2.24 l	33.18 l	364.00 l
P_1Ca_2	17.33 kl	2.28 kl	35.61 k	384.00 kl
P_1Ca_3	18.43 i-k	2.37 i-k	37.52 ij	420.00 i-k
P_1Ca_4	17.81 j-l	2.31 j-l	36.82 jk	404.00 j-l
P_2Ca_1	18.87 h-j	2.40 h-j	38.67 hi	444.00 h-j
P_2Ca_2	20.50 fg	2.49 e-h	40.93 g	504.00 fg
P_2Ca_3	21.33 d-f	2.53 c-g	43.92 ef	560.00 e
P_2Ca_4	20.81 e-g	2.50 d-g	42.85 f	536.00 ef
P_3Ca_1	19.33 hi	2.43 g-i	39.55 gh	460.00 g-i
P_3Ca_2	21.75 c-e	2.55 c-f	44.53 de	588.00 de
P_3Ca_3	22.65 bc	2.63 bc	46.92 bc	676.00 ab
P_3Ca_4	22.22 cd	2.60 b-d	45.62 cd	652.00 bc
P_4Ca_1	19.72 gh	2.45 f-i	40.18 gh	484.00 f-h
P_4Ca_2	22.00 cd	2.58 c-e	45.00 de	616.00 cd
P_4Ca_3	24.14 a	2.75 a	49.33 a	716.00 a
P_4Ca_4	23.35 ab	2.69 ab	47.67 b	652.00 ab
$LSD_{(0.05)}$	**1.16**	**0.09**	**1.39**	**53.77**
CV(%)	**3.39**	**2.27**	**1.98**	**6.01**

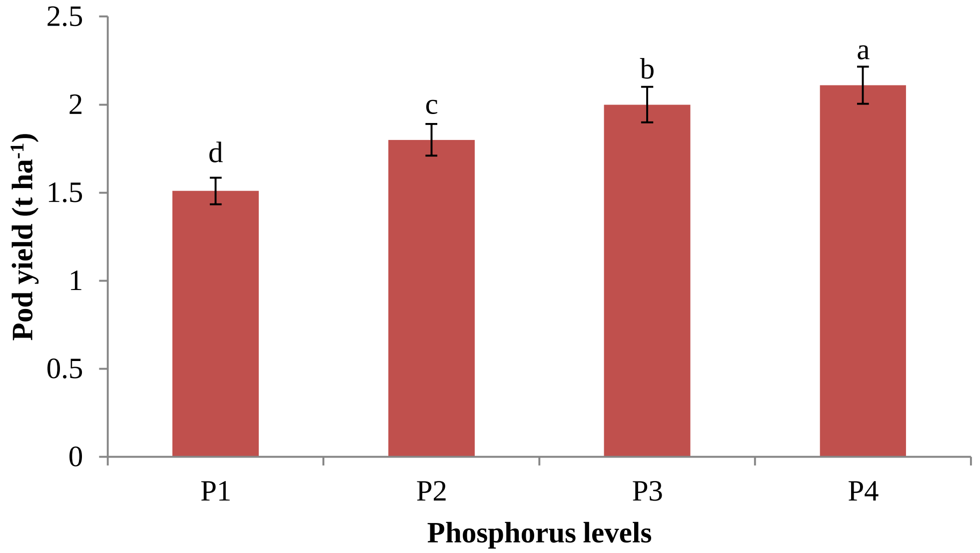
In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Here, P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}; Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

4.8 Pod yield

4.8.1 Effect of phosphorus

Different levels of phosphorus exerted significant variation on pod yield (t ha^{-1}) of groundnut (Figure 15). From the experiment result revealed that the maximum pod yield (2.11 t ha^{-1}) was obtained from P_4 treatment while the minimum pod yield (1.51 t ha^{-1}) was obtained from P_1 treatment. The result of the experiment was also in coincided by Everest *et al.* (2022) reported that pod yield enhanced significantly by 15.4%, 27.3% and 39.9% with increase in fertilization rates from 40 kg to 80 kg ha^{-1} compare to unfertilized plots. Tekulu *et al.* (2020) reported that Average pod yield increased by 85.4% for a combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} fertilizers compared to the control plots. Hasan *et al.* (2019) revealed that vegetative growth and yield of the plant was better at $N_{30}P_{60}$ kg ha^{-1} than the all other treatments. Vali *et al.* (2020) reported that treatment receiving 50 kg phosphorus + 30 kg zinc ha^{-1} were more productive and economic for the pod production of groundnut.

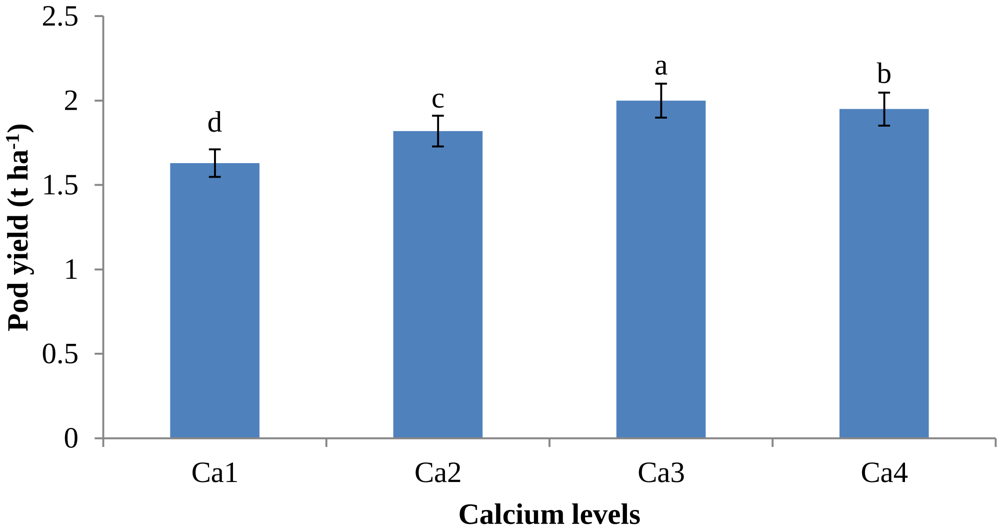


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 15. Effect of phosphorus on pod yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.05; vertical bars represent LSD value).

4.8.2 Effect of calcium

Different levels of calcium application revealed significant influence on pod yield (t ha^{-1}) of groundnut under this experiment (Figure 16). From the experiment result showed that the maximum pod yield of groundnut was obtained from Ca_3 (2.00 t ha^{-1}) treatment. On the other hand the minimum pod yield of groundnut was obtained from Ca_1 (1.63 t ha^{-1}) treatment. The finding of the experiment was coincided with the findings of Kabir *et al.* (2013) reported that the fertilizer level for Ca should be 110 kg ha^{-1} for obtaining the highest yield of groundnut. Kamara *et al*. (2011) reported that calcium application significantly influenced pod yields. Application of 100 kg Ca ha^{-1} resulted in highest (3076 kg ha^{-1}) pod yield whereas control gives the lowest one. Petro and Ray (2016) reported that split applications of gypsum significantly improved pod yield and yield attributes as well as economics of groundnut. Ramya *et al.* (2022) also reported that the application of 400 kg ha^{-1} gypsum increased the yield contributing features.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 16. Effect of calcium on pod yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.05; vertical bars represent LSD value).

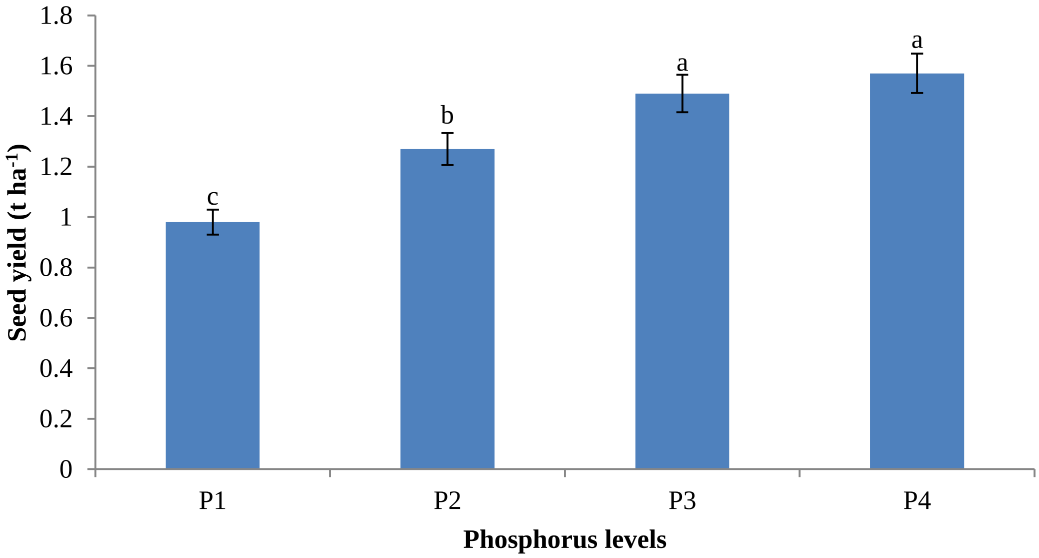
4.8.3 Combined effect of phosphorus and calcium

Combined effect of phosphorus and calcium showed significant influence on pod yield of groundnut under the present study (Table 5 Appendix IX). Result from the experiment revealed that the maximum pod yield of groundnut (2.36 t ha^{-1}) was obtained from P_4Ca_3 treatment combination which was statistically identical to P_4Ca_4 (2.30 t ha^{-1}) treatment combination. On the other hand the minimum pod yield of groundnut (1.44 t ha^{-1}) was obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 (1.48 t ha^{-1}) and P_1Ca_4 (1.53 t ha^{-1}) treatment combinations.

4.9 Seed yield

4.9.1 Effect of phosphorus

Different levels of phosphorus exerted significant variation on seed yield (t ha^{-1}) of groundnut (Figure 17). From the experiment result revealed that the maximum seed yield (1.57 t ha^{-1}) was obtained from P_4 treatment which was statistically similar with P_3 treatment while the minimum seed yield (0.98 t ha^{-1}) was obtained from P_1 treatment. The result of the experiment was also in coincided by Tekulu *et al.* (2020) reported that average pod yield increased by 85.4% for a combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} fertilizers compared to the control plots. Vali *et al.* (2020) reported that treatment receiving 50 kg phosphorus + 30 kg zinc ha^{-1} were more productive and economic for the pod production of groundnut. Hasan *et al.* (2019) revealed that vegetative growth and yield of the plant was better at $N_{30}P_{60}$ kg ha^{-1} than the control treatment.

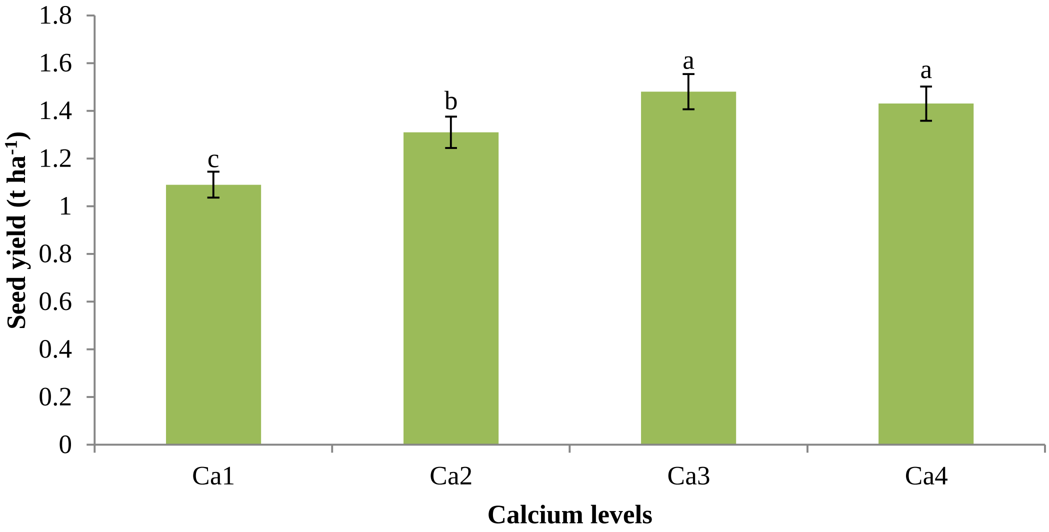


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 17. Effect of phosphorus on seed yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.08).

4.9.2 Effect of calcium

Different levels of calcium application revealed significant influence on seed yield (t ha^{-1}) of groundnut under this experiment (Figure 18). From the experiment result showed that the maximum seed yield of groundnut was obtained from Ca_3 (1.48 t ha^{-1}) treatment which was statistically identical to Ca_4 treatment. On the other hand the minimum seed yield of groundnut was obtained from Ca_1 (1.09 t ha^{-1}) treatment. The finding of the experiment was coincided with the findings of Kabir *et al.* (2013) reported that the fertilizer level for Ca should be 110 kg ha^{-1} for obtaining the highest yield of groundnut. Petro and Ray (2016) reported that split applications of gypsum significantly improved pod yield and yield attributes as well as economics of groundnut. Kamara *et al.* (2011) reported that calcium application significantly influenced seed yields.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 18. Effect of calcium on seed yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.06; vertical bars represent LSD value).

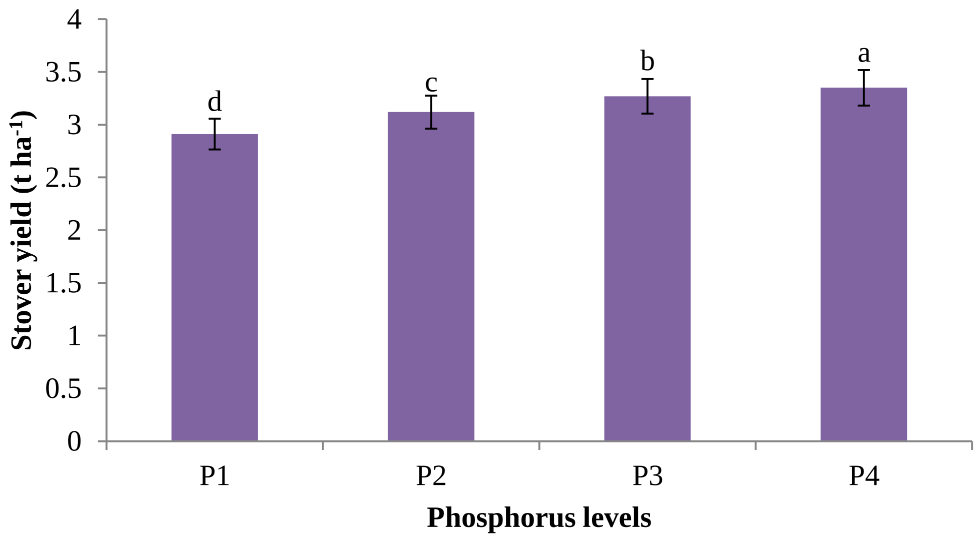
4.9.3 Combined effect of phosphorus and calcium

Combined effect of phosphorus and calcium showed significant influence on seed yield of groundnut under the present study (Table 5 Appendix IX). Result from the experiment revealed that the maximum seed yield of groundnut (1.79 t ha^{-1}) was obtained from P_4Ca_3 treatment combination which was statistically followed by P_4Ca_4 (1.73 t ha^{-1}) and P_3Ca_3 (1.69 t ha^{-1}) treatment combination. On the other hand the minimum seed yield of groundnut (0.91 t ha^{-1}) was obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 (0.96 t ha^{-1}) and P_1Ca_4 (1.01 t ha^{-1}) treatment combinations.

4.10 Stover yield

4.10.1 Effect of phosphorus

Stover yield of groundnut showed significant variation due to the effect of different phosphorus levels (Figure 19). From the experiment result revealed that the maximum stover yield of groundnut (3.35 t ha^{-1}) was obtained from P_4 treatment while the minimum stover yield of groundnut (2.91 t ha^{-1}) was obtained from P_1 treatment. Similar trends also observed by Mouri *et al.* (2018) reported that increasing P levels significantly increased number of pods $plant^{-1}$, weight of pods $plant^{-1}$, weight of seeds $plant^{-1}$, 100-seed weight, pod yield, seed yield and stover yield of groundnut.

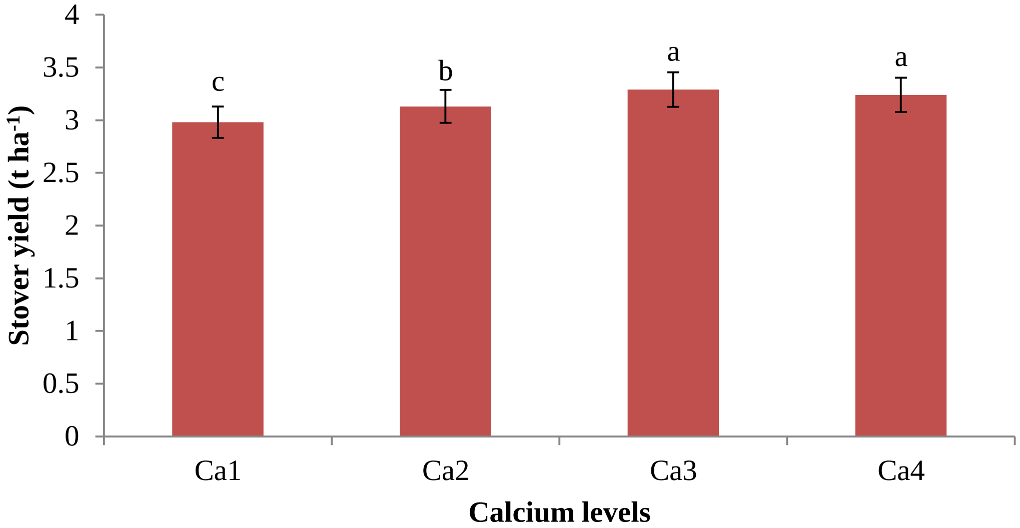


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 19. Effect of phosphorus on stover yield $hectare^{-1}$ of groundnut ($LSD_{0.05}$= 0.07; vertical bars represent LSD value).

4.10.2 Effect of calcium

Significant variation was observed on stover yield (t ha^{-1}) of groundnut due to different levels of calcium application under this experiment (Figure 20). From the experiment result showed that the maximum stover yield of groundnut (3.29 t ha^{-1}) was obtained from Ca_3 treatment which was statistically identical to Ca_4 (3.24 t ha^{-1}) treatment. On the other hand, the minimum stover yield of groundnut was obtained from Ca_1 (2.98 t ha^{-1}) treatment. The finding of the experiment was coincided with the findings of Kabir *et al.* (2013) who reported that fertilizer doses of Ca at the rate of 110 kg ha^{-1} increases pod yield, biological yield, straw yield and harvest index. Yadav *et al.* (2015) found that maximum yield was recorded with treatment T_2 (gypsum @ 200 kg ha^{-1}) while minimum yield was recorded with treatment T_0 (no fertilizer and gypsum).



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 20. Effect of calcium on stover yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.06).

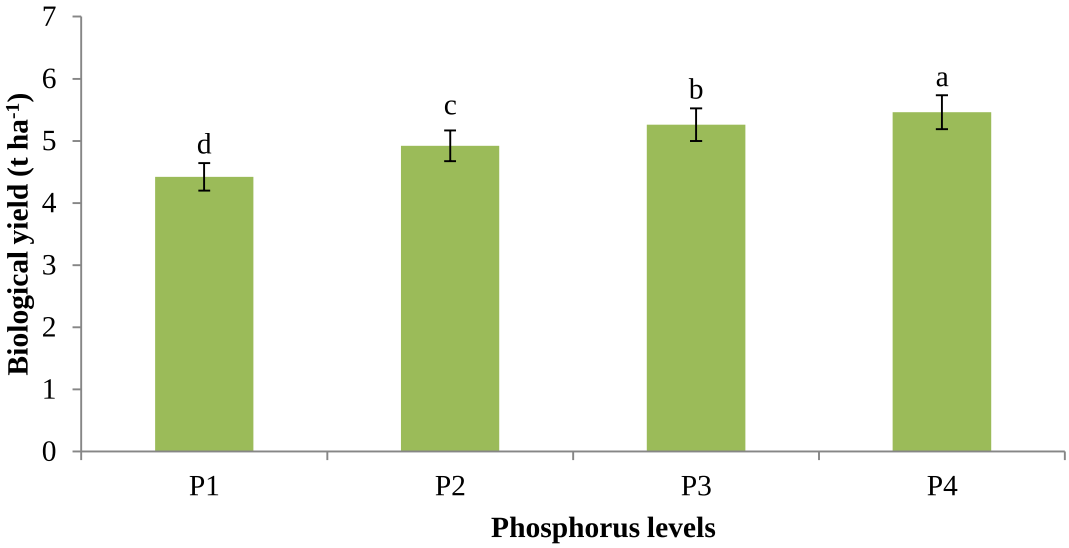
4.10.3 Combined effect of phosphorus and calcium

Combined effect of phosphorus and calcium showed significant difference on stover yield of groundnut under the present study (Table 5 and Appendix IX). Result from the experiment revealed that the maximum stover yield of groundnut (3.52 t ha^{-1}) was obtained from P_4Ca_3 treatment combination which was statistically as par with P_4Ca_4 (3.49 t ha^{-1}) and P_3Ca_3 (3.43 t ha^{-1}) treatment combinations. On the other hand the minimum stover yield of groundnut (2.82 t ha^{-1}) was obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 (2.88 t ha^{-1}) treatment combination.

4.11 Biological yield

4.11.1 Effect of phosphorus

Different levels of phosphorus application exerted significant influence on biological yield of groundnut (Figure 21). From the experiment result revealed that the maximum biological yield of groundnut (5.46 t ha^{-1}) was obtained from P_4 treatment. On the other hand the minimum biological yield of groundnut (4.41 t ha^{-1}) was achieved from P_1 treatment. The result of the experiment was in coincided with the findings of Sharma *et al.* (2020) who reported that phosphorus fertilizer along with vermicompost increase the pod yield, biological yield and harvest index of groundnut. Mouri *et al.* (2018) reported that variety BARI Cheenabadam-8 should preferably be fertilized with 60 kg P ha^{-1} to obtain the highest yield.

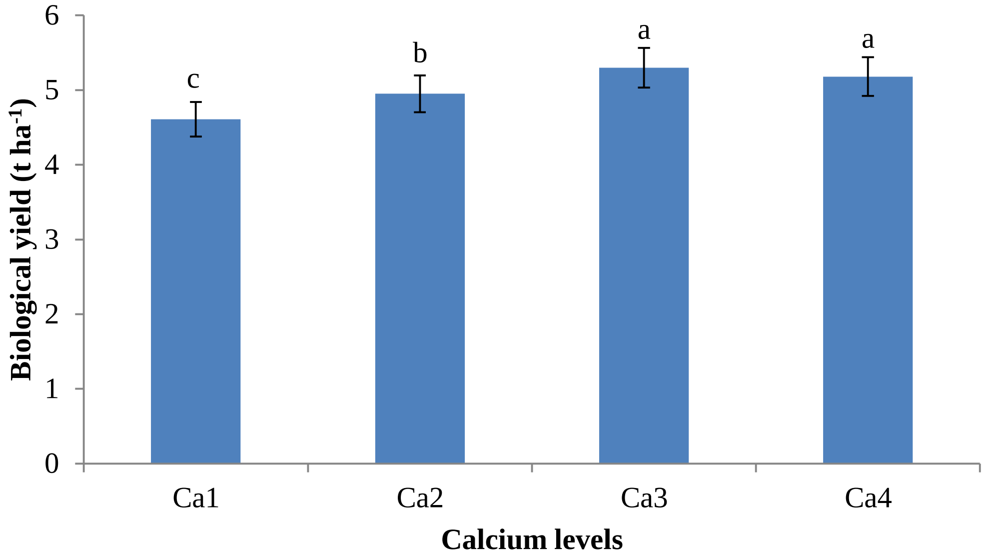


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 21. Effect of phosphorus on biological yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.07; vertical bars represent LSD).

4.11.2 Effect of calcium

Significant effect on biological yield was observed due to different levels of calcium application under the present study (Figure 22). From the experiment result showed that the maximum biological yield of groundnut was observed in Ca_3 (5.30 t ha^{-1}) treatment which was statistically identical to Ca_4 (5.18 t ha^{-1}) treatment. On the other hand the minimum biological yield of groundnut was obtained from Ca_1 (4.61 t ha^{-1}) treatment. Similar result also found by Kabir *et al.* (2013) who reported that the combined dose of P_2, Ca_1 and B_2 produced the highest values for almost all the growth, yield and yield contributing parameters. Thus, it can be concluded that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 22. Effect of calcium on biological yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.06).

4.11.3 Combined effect of phosphorus and calcium

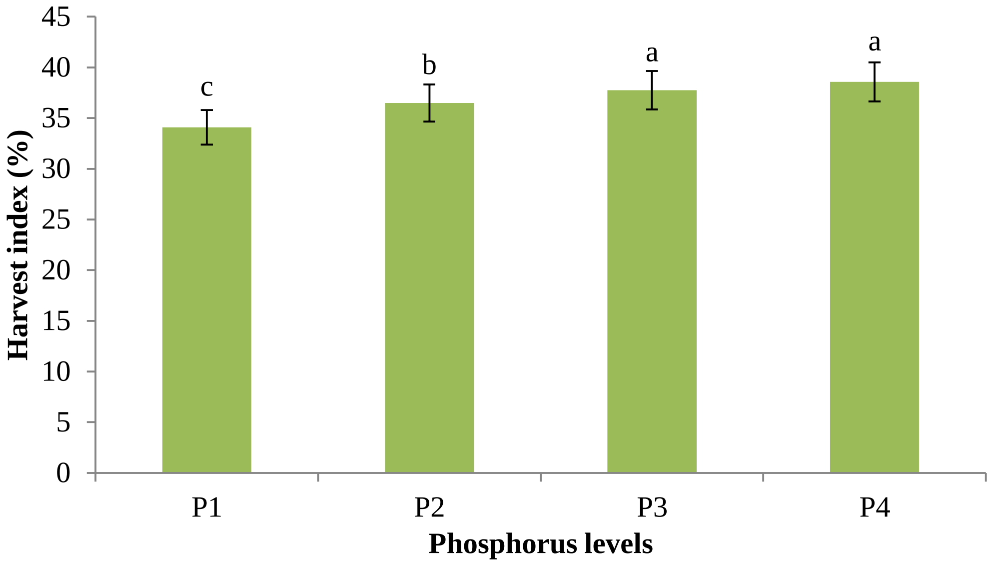
Combined effect of phosphorus and calcium showed significant difference on biological yield (t ha^{-1}) of groundnut under the study (Table 5 and Appendix IX). Result revealed that the maximum biological yield of groundnut (5.88 t ha^{-1}) was achieved from P_4Ca_3 treatment combination which was statistically identical to P_4Ca_4 (5.79 t ha^{-1}) while the minimum biological yield of groundnut (4.26 t ha^{-1}) was observed in P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 treatment combinations.

4.12 Harvest index

4.12.1 Effect of phosphorus

Harvest index (%) of groundnut revealed significant difference due to effect of different levels of phosphorus application (Figure 23). Result from the experiment noted that the maximum harvest index of groundnut (38.56%) was obtained from P_4

treatment which was statistically identical to P_3 (37.75%) treatment. On the other hand the minimum harvest index of groundnut (34.10%) was observed in P_1 treatment. Similar result was also observed by Lincoln *et al.* (2022) reported that pod yield, seed yield, haulm yield and harvest index were recorded significantly higher with the application of $ZnSO_4$ 30 kg ha^{-1} + Phosphorus 60 kg ha^{-1} as compared to other treatments. Tekulu *et al.* (2020) reported that the highest N harvest index was obtained for control treatments and for plots treated with combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}.

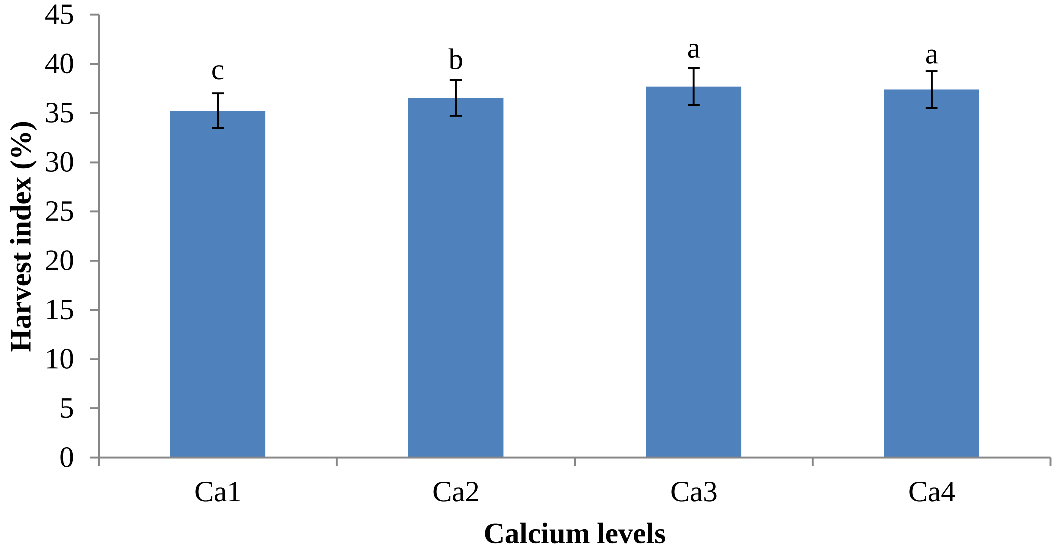


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 23. Effect of phosphorus on harvest index of groundnut ($LSD_{0.05}$= 0.91).

4.12.2 Effect of calcium

Statistically significant variation on harvest index (%) of groundnut was observed due to different levels of calcium application (Figure 24). From the experiment result showed that the maximum harvest index of groundnut was obtained from Ca_3 (37.71%) treatment which was statistically identical to Ca_4 (37.39%) treatment. On the other hand the minimum harvest index of groundnut was obtained from Ca_1 (35.24%) treatment. Similar result was also found by Kabir *et al.* (2013) who reported that the combined dose of P_2, Ca_1 and B_2 produced the highest values for almost all the growth, yield (pod yield, straw yield, biological yield and harvest index) and yield contributing parameters. Thus, it can be concluded that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 24. Effect of calcium on harvest index of groundnut ($LSD_{0.05}$= 0.63).

4.12.3 Combined effect of phosphorus and calcium

Different levels of phosphorus along with different levels of calcium application showed significant difference on harvest index (%) of groundnut (Table 5 and Appendix IX). Result revealed that the maximum harvest index of groundnut (40.14%) was obtained from P_4Ca_3 treatment combination which was statistically similar with P_4Ca_4 (39.72%) and P_3Ca_3 (38.97%) treatment combinations. On the other hand the minimum harvest index of groundnut (33.80%) was obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 (33.94%), P_1Ca_4 (34.16%) and P_1Ca_3 (34.51%) treatment combinations under the study.

Table 5. Combined effect of phosphorus and calcium on pod yield, seed yield, stover yield, biological yield and harvest index of groundnut

Treatment Combinations	Pod yield ($t\ ha^{-1}$)	Seed yield ($t\ ha^{-1}$)	Stover yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
P_1Ca_1	1.44 k	0.91 k	2.82 j	4.26 k	33.80 l
P_1Ca_2	1.48 jk	0.96 jk	2.88 ij	4.36 jk	33.94 kl
P_1Ca_3	1.57 ij	1.05 ij	2.98 g-i	4.55 ij	34.51 j-l
P_1Ca_4	1.53 i-k	1.01 i-k	2.95 hi	4.48 jk	34.16 kl
P_2Ca_1	1.63 hi	1.11 hi	2.99 g-i	4.62 h-j	35.28 i-k
P_2Ca_2	1.79 fg	1.26 fg	3.12 ef	4.91 fg	36.46 f-i
P_2Ca_3	1.91 e	1.40 de	3.22 de	5.13 d-f	37.23 e-g
P_2Ca_4	1.85 ef	1.34 ef	3.15 ef	5.00 e-g	37.00 e-h
P_3Ca_1	1.70 gh	1.15 g-i	3.05 f-h	4.75 g-i	35.78 h-j
P_3Ca_2	1.95 de	1.47 de	3.24 de	5.19 de	37.57 d-f
P_3Ca_3	2.19 b	1.69 ab	3.43 ab	5.62 ab	38.97 a-c
P_3Ca_4	2.12 bc	1.63 bc	3.36 bc	5.48 bc	38.69 b-d
P_4Ca_1	1.74 g	1.21 f-h	3.08 fg	4.82 gh	36.09 g-i
P_4Ca_2	2.04 cd	1.54 cd	3.29 cd	5.33 cd	38.27 c-e
P_4Ca_3	2.36 a	1.79 a	3.52 a	5.88 a	40.14 a
P_4Ca_4	2.30 a	1.73 ab	3.49 a	5.79 a	39.72 ab
$LSD_{(0.05)}$	**0.10**	**0.13**	**0.11**	**0.23**	**1.27**
CV(%)	**3.46**	**6.18**	**2.20**	**2.84**	**2.06**

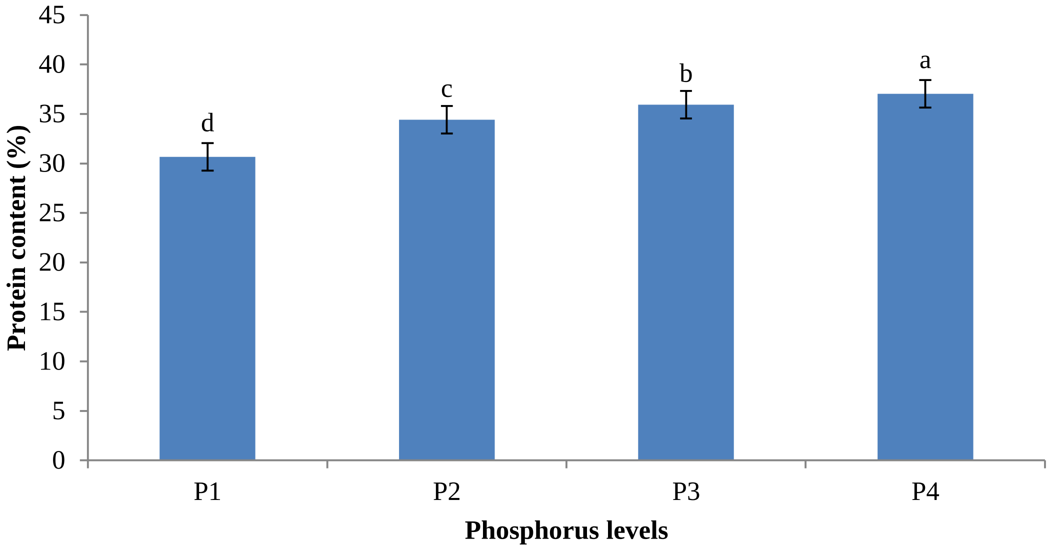
In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Here, P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}; Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

4.13 Protein content

4.13.1 Effect of phosphorus

Different levels of phosphorus application showed significant variation on protein content (%) of groundnut (Figure 25). Result from the experiment noted that the maximum protein content of groundnut (37.04%) was obtained from P_4 treatment while the minimum protein content of groundnut (30.66%) was observed in P_1 treatment. Similar result was also observed by Everest *et al.* (2022) who reported that protein and oil content showed a positive response with phosphorus application. Meresa *et al.* (2020) reported that the percentage of crude protein and fat content had significantly affected by phosphorus and zinc components.

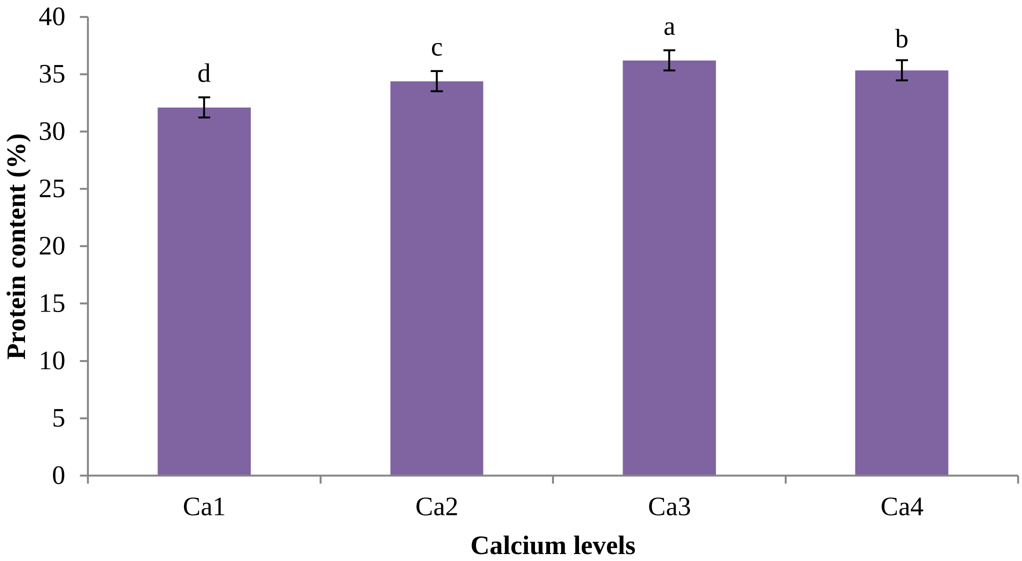


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 25. Effect of phosphorus on protein content of groundnut ($LSD_{0.05}$= 0.73; vertical bars represent LSD value).

4.13.2 Effect of calcium

Significant influence on protein content (%) of groundnut was observed due to the application of different calcium levels (Figure 26). From the experiment result showed that the maximum protein content of groundnut was obtained from Ca_3 (36.20%) treatment. On the other hand the minimum protein content of groundnut was obtained from Ca_1 (32.10%) treatment. Similar result was also found by Rao and Shaktawat (2001) who reported that oil and protein content of groundnut kernel increased significantly under gypsum treatments.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 26. Effect of calcium on protein content of groundnut ($LSD_{0.05}$= 0.61; vertical bars represent LSD value).

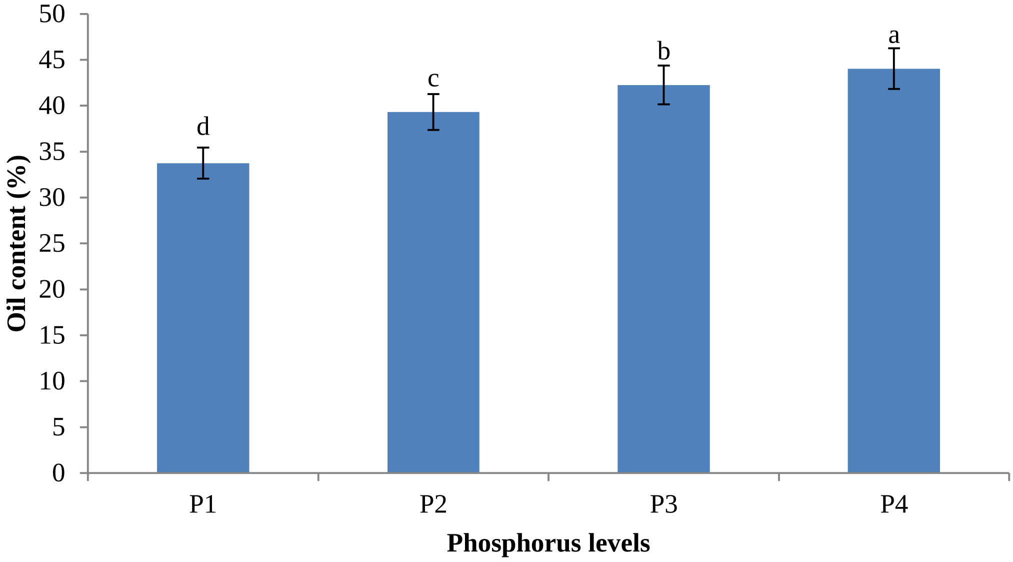
4.13.3 Combined effect of phosphorus and calcium

Protein content (%) of groundnut showed significant difference due to the combined effect of phosphorus and calcium under the study (Table 6 and Appendix X). Result revealed that the maximum protein content of groundnut (39.63%) was obtained from P_4Ca_3 treatment combination. On the other hand the minimum protein content of groundnut (29.41%) was obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 treatment combinations.

4.14 Oil content

4.14.1 Effect of phosphorus

Significant influence on oil content (%) of groundnut was observed due to effect of different levels of phosphorus application under the present study (Figure 27). Result from the experiment noted that the maximum oil content of groundnut (44.04%) was obtained from P_4 treatment. On the other hand the minimum oil content of groundnut (33.74%) was observed in P_1 treatment. Similar result was also observed by Tekulu *et al.* (2020) who reported that combined application of 15 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} was recommended for increasing grain yield, grain protein content, oil content and residual soil nitrogen.

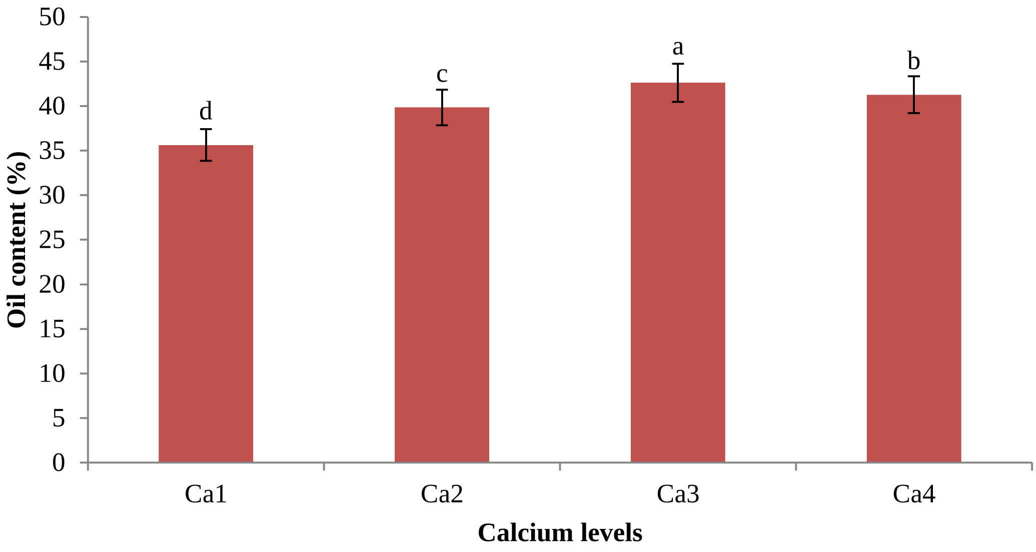


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 27. Effect of phosphorus on oil content of groundnut ($LSD_{0.05}$= 0.61; vertical bars represent LSD value).

4.14.2 Effect of calcium

Significant effect on oil content (%) of groundnut was observed due to calcium under the study (Figure 28). From the experiment result showed that the maximum oil content of groundnut was obtained from Ca_3 (42.61%) treatment. On the other hand the minimum oil content of groundnut was obtained from Ca_1 (35.62%) treatment. Similar result was also found by Hamza *et al.* (2021) who revealed that protein content, oil content and oil yield of groundnut was significantly increased over the control due to application of calcium. Peanuts may benefit from Ca^{2+} better by using gypsum as the soil application and calcium nitrate as the foliar application to prevent disorders of Ca^{2+} deficiency under sandy soil conditions.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 28. Effect of calcium on oil content of groundnut ($LSD_{0.05}$= 0.92; vertical bars represent LSD value).

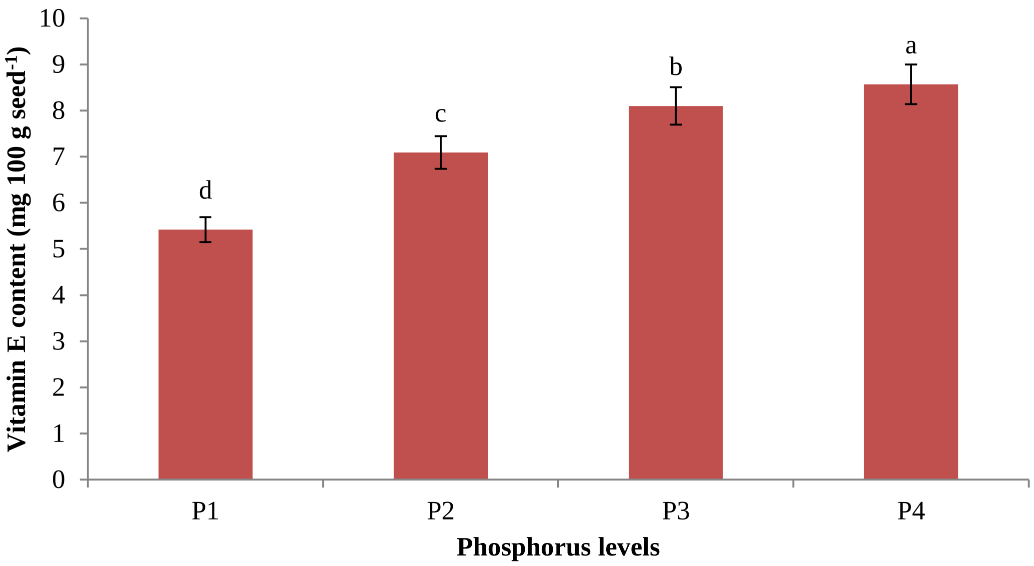
4.14.3 Combined effect of phosphorus and calcium

Combined effect of different phosphorus levels along with different calcium showed significant difference on oil content (%) of groundnut (Table 6 and Appendix X). Result revealed that the maximum oil content of groundnut (48.25%) was obtained from P_4Ca_3 treatment combination. On the other hand the minimum oil content of groundnut (32.41%) was obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 (33.53%) and P_1Ca_4 (34.09%) treatment combinations.

4.15 Vitamin E content

4.15.1 Effect of phosphorus

Significant influence was observed on vitamin E content (mg 100 g $seed^{-1}$) of groundnut due to effect of different levels of phosphorus application (Figure 29). Result from the experiment noted that the maximum vitamin E content of groundnut (8.57 mg 100 g $seed^{-1}$) was obtained from P_4 treatment. On the other hand the minimum vitamin E content of groundnut (5.42 mg 100 g $seed^{-1}$) was observed in P_1 treatment. Similar result was also observed by Gobarah *et al.* (2006) who reported that foliar spraying with phosphorus levels had a significant effect on groundnut growth, yield and its components as well as seed quality. It was observed that the most of the characters under study increased significantly by the interaction between phosphorus fertilizer and foliar spraying with phosphorus expect dry weight of stem, P and oil percentages.

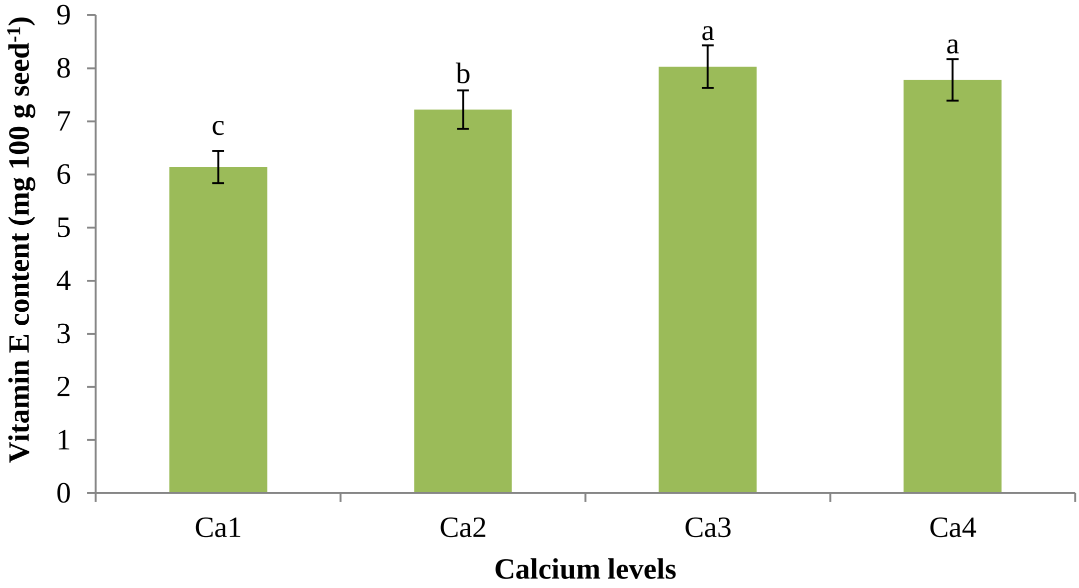


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 29. Effect of phosphorus on vitamin E content of groundnut ($LSD_{0.05}$= 0.38; vertical bars represent LSD).

4.15.2 Effect of calcium

Significant effect on vitamin E content (mg 100 g seed^{-1}) of groundnut was observed due to different levels of calcium application under the study (Figure 30). From the experiment result showed that the maximum vitamin E content of groundnut was obtained from Ca_3 (8.03 mg 100 g seed^{-1}) treatment which was statistically identical to Ca_4 (7.78 mg 100 g seed^{-1}). On the other hand the minimum vitamin E content of groundnut was obtained from Ca_1 (6.14 mg/100 seed) treatment. Similar result was also found by Rajanarasimha *et al.* (2021) who reported that the application of gypsum significantly increased the growth parameters, yield attributes, yield, nutrient content, uptake, and quality parameters of summer groundnut (*Arachis hypogaea* L.)



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 30. Effect of calcium on vitamin E content of groundnut ($LSD_{0.05}$= 0.38).

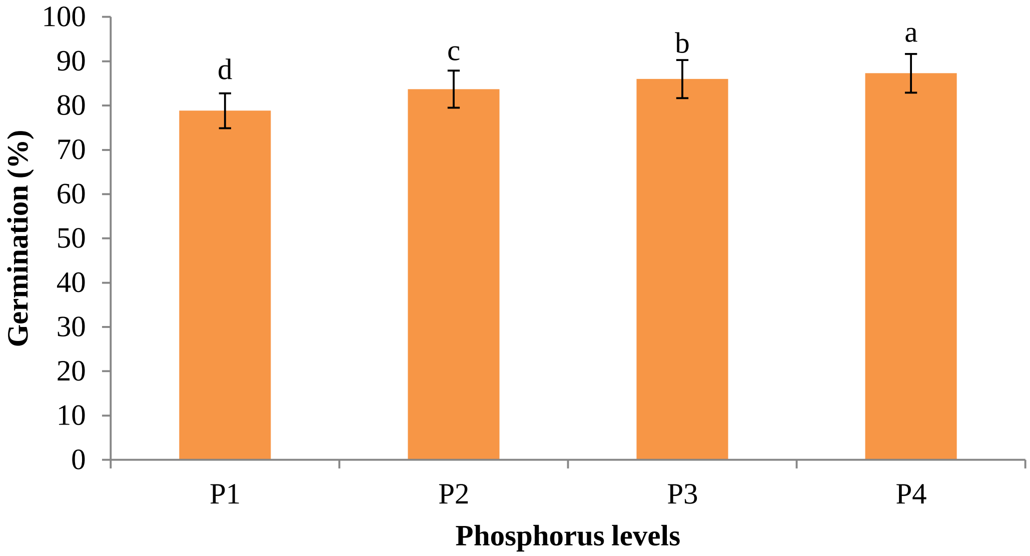
4.15.3 Combined effect of phosphorus and calcium

Different phosphorus levels along with different calcium showed significant variation on vitamin E content (mg 100 g seed^{-1}) of groundnut (Table 6 and Appendix X). Result revealed that the maximum vitamin E content of groundnut (9.69 mg 100 g seed^{-1}) was obtained from P_4Ca_3 treatment combination which was statistically similar with P_4Ca_4 and P_3Ca_3 treatment combinations. On the other hand the minimum vitamin E content of groundnut (4.97 mg 100 g seed^{-1}) was obtained from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 and P_1Ca_4 treatment combinations.

4.16 Germination percentage

4.16.1 Effect of phosphorus

Significant influence on germination (%) of groundnut was found due to the effect of different levels of phosphorus application under the present study (Figure 31). Result from the experiment noted that the maximum germination of groundnut (87.28%) was obtained from P_4 treatment. On the other hand the minimum germination of groundnut (78.85%) was observed in P_1 treatment. Similar result was also observed by Naabe *et al.* (2021) who reported that seed quality parameters significantly increased with the application of phosphorus fertilizer.

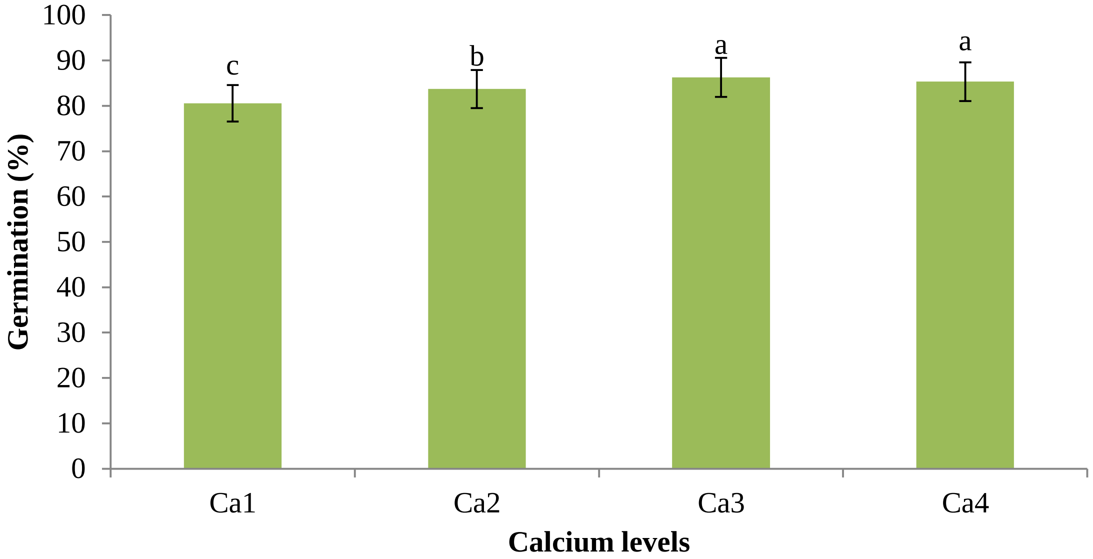


P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}

Figure 31. Effect of phosphorus on germination percentage of groundnut ($LSD_{0.05}$= 0.85; vertical bars represent LSD value).

4.16.2 Effect of calcium

Significant variation on germination of groundnut (%) of groundnut was observed due to the effect of different levels of calcium application (Figure 32). From the experiment result showed that the maximum germination of groundnut (86.28%) was obtained from Ca_3 treatment which was statistically identical to Ca_4 (85.32%) treatment. On the other hand the minimum germination of groundnut was obtained from Ca_1 (80.55%) treatment. Similar result was also found by Rao and Shaktawat (2001) who reported oil content, protein content and germination percentage of groundnut kernel increased significantly under gypsum treatments.



Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

Figure 30. Effect of calcium on germination percentage of groundnut ($LSD_{0.05}$= 1.05).

4.16.3 Combined effect of phosphorus and calcium

Combined effect of different levels of phosphorus along with different levels of calcium application showed significant influence on germination (%) of groundnut (Table 6 and Appendix X). Result revealed that the maximum germination of groundnut (90.70%) was obtained from P_4Ca_3 treatment combination which was statistically similar with P_4Ca_4 (89.80%) treatment combinations where the minimum germination of groundnut (76.60%) was recorded from P_1Ca_1 treatment combination which was statistically similar with P_1Ca_2 (78.50%) treatment combinations.

Table 6. Combined effect of phosphorus and calcium on protein content, oil content, vitamin E content and germination percentage of groundnut

Treatment Combinations	Protein content (%)	Oil content (%)	Vitamin E content (mg 100 g seed^{-1})	Germination (%)
P_1Ca_1	29.41 l	32.41 l	4.97 k	76.60 l
P_1Ca_2	30.52 kl	33.53 kl	5.33 jk	78.50 kl
P_1Ca_3	31.67 i-k	34.95 i-k	5.75 ij	80.60 i-k
P_1Ca_4	31.05 jk	34.09 j-l	5.62 i-k	79.70 jk
P_2Ca_1	32.18 ij	35.77 ij	6.11 hi	81.50 ij
P_2Ca_2	34.71 fg	39.55 g	7.15 fg	83.90 gh
P_2Ca_3	35.67 d-f	41.63 ef	7.72 d-f	85.20 e-g
P_2Ca_4	35.05 e-g	40.28 fg	7.37 e-g	84.30 fg
P_3Ca_1	32.95 hi	36.51 hi	6.67 gh	81.90 hi
P_3Ca_2	36.00 d-f	42.58 de	8.00 de	86.00 d-f
P_3Ca_3	37.81 bc	45.62 bc	8.97 a-c	88.60 bc
P_3Ca_4	36.95 cd	44.31 cd	8.77 bc	87.50 cd
P_4Ca_1	33.87 gh	37.82 h	6.81 gh	82.20 hi
P_4Ca_2	36.33 de	43.72 d	8.42 cd	86.40 de
P_4Ca_3	39.63 a	48.25 a	9.69 a	90.70 a
P_4Ca_4	38.32 b	46.36 b	9.35 ab	89.80 ab
$LSD_{(0.05)}$	**1.23**	**1.85**	**0.76**	**2.10**
CV(%)	**2.12**	**2.27**	**6.22**	**1.49**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Here, P_1= 0 kg P ha^{-1}, P_2= 29 kg P ha^{-1}, P_3= 32 kg P ha^{-1} and P_4= 35 kg P ha^{-1}; Ca_1= 0 kg Ca ha^{-1}, Ca_2= 55 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 65 kg Ca ha^{-1}

CHAPTER V

SUMMARY AND CONCLUSION

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The experiment was carried out at the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during April 2021 to August 2021 to determine the effect of phosphorus and calcium on yield and seed quality of groundnut cv. BARI cheenabadam-10. The experiment consisted of two factors. Factor A: Phosphorus fertilizer (4 levels) *viz.*, P_1= 0 kg P ha^{-1} (0 kg TSP ha^{-1}), P_2= 29 kg P ha^{-1} (145 kg TSP ha^{-1}), P_3= 32 kg P ha^{-1} (160 kg TSP ha^{-1}) and P_4= 35 kg P ha^{-1} (175 kg TSP ha^{-1}) and factor B: Calcium fertilizer (4 levels) *viz.*, Ca_1= 0 kg Ca ha^{-1} (0 kg gypsum ha^{-1}), Ca_2= 55 kg Ca ha^{-1} (275 kg gypsum ha^{-1}), Ca_3= 60 kg Ca ha^{-1} (300 kg gypsum ha^{-1}) and Ca_4= 65 kg Ca ha^{-1} (325 kg gypsum ha^{-1}). The experiment was laid out in split-plot design with three replications. There were 16 treatment combinations. The total numbers of unit plots were 48. The size of unit plot was 4.00 m^2 (2.00 m × 2.00 m). Phosphorus fertilizer was placed along the main plot and calcium fertilizer was placed along the sub plot. The groundnut seeds were sown in lines maintaining a line to line distance of 30 cm and plant to plant distance of 15 cm having 2 seeds hole^{-1}. The data on different growth, yield contributing parameters, yield and seed quality of groundnut were recorded and statistically analysed.

Different growths, yield contributing parameters, yield and seed quality were significantly influenced by different phosphorus levels. Results revealed that the maximum plant height (15.06, 21.57, 33.23, 42.76 and 45.79 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (15.08, 30.69, 38.41, 42.73 and 39.18 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (3.50, 6.41, 7.58, 8.10 and 7.87 at 25, 50, 75, 100 DAS and at harvest, respectively), number of pods plant^{-1} (22.30), pod length (2.62 cm), 100 seeds weight (45.55 g), seed yield plot^{-1} (627.00 g), pod yield (2.11 t ha^{-1}), seed yield (1.57 t ha^{-1}), stover yield (3.35 t ha^{-1}), biological yield (5.46 t ha^{-1}), harvest index (38.56%), protein content (37.04%), oil content (44.04%), vitamin E content (8.57 mg 100 g seed^{-1}) and germination (87.28%) were obtained from P_4 treatment. On the other hand the minimum plant height (12.44, 17.25, 26.53, 35.41 and 38.69 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (11.44, 22.52, 27.00, 31.27 and 27.88 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (2.08, 4.63, 6.04, 6.38 and 5.89 at 25, 50, 75, 100 DAS and at harvest, respectively), number of pods plant^{-1} (17.55), pod length (2.30 cm), 100 seeds weight (35.78 g), seed yield plot^{-1} (393.00 g), pod yield (1.51 t ha^{-1}), seed yield (0.98 t ha^{-1}), stover yield (2.91 t ha^{-1}), biological yield (4.41 t ha^{-1}), harvest index (34.10%), protein content (30.66%), oil content (33.74%), vitamin E content (5.42 mg 100 g seed^{-1}) and germination (78.85%) were observed in P_1 treatment.

Growth, yield contributing parameters, yield and seed quality was significantly influenced by different levels of calcium application. In case of calcium application, results revealed that the maximum plant height (14.63, 21.07, 32.27, 41.73 and 44.72 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (14.58, 29.77, 36.72, 41.29 and 37.46 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (3.29, 6.16, 7.38, 7.86 and 7.62 at 25, 50, 75, 100 DAS and at harvest, respectively), number of pods plant^{-1} (21.64), pod length (2.57 cm), 100 seeds weight (44.42 g), seed yield plot^{-1} (593.00 g), pod yield (2.00 t ha^{-1}), seed yield (1.48 t ha^{-1}), stover yield (3.29 t ha^{-1}), biological yield (5.30 t ha^{-1}), harvest index (37.71%), protein content (36.20%), oil content (42.61%), vitamin E content (8.03 mg 100 g seed^{-1}) and germination (86.28%) were obtained from Ca_3 treatment. On the other hand the minimum plant height (12.86, 18.41, 28.49, 36.97 and 40.24 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (12.27, 25.32, 28.86, 33.09 and 30.29 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (2.37, 4.98, 6.38, 6.74 and 6.28 at 25, 50, 75, 100 DAS and at harvest, respectively), number of pods plant^{-1} (18.64), pod length (2.38 cm), 100 seeds weight (37.89 g), pod yield plot^{-1} (438.00 g), pod yield (1.63 t ha^{-1}), seed yield (1.09 t ha^{-1}), stover yield (2.98 t ha^{-1}), biological yield (4.61 t ha^{-1}), harvest index (35.24%), protein content (32.10%), oil content (35.62%), vitamin E content (6.14 mg 100 g seed^{-1}) and germination (80.55%) were observed in Ca_1 treatment.

Combined effect of phosphorus and calcium fertilization showed significant influence on growth, yield contributing characters, yield and seed quality of groundnut. Results revealed that the maximum plant height (16.62, 23.33, 35.75, 45.81 and 48.33 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (16.50, 33.33, 42.81, 47.00 and 43.75 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (4.00, 7.15, 8.33, 8.75 and 8.67 at 25, 50, 75, 100 DAS and at harvest, respectively), number of pods plant^{-1} (24.14), pod length (2.75 cm), 100 seeds weight (49.33 g), seed yield plot^{-1} (716.00 g), pod yield (2.36 t ha^{-1}), seed yield (1.79 t ha^{-1}), stover yield (3.52 t ha^{-1}), biological yield (5.88 t ha^{-1}), harvest index (40.14%), protein content (39.63%), oil content (48.25%), vitamin E content (9.69 mg 100 g seed^{-1}) and germination (90.70%) were obtained from P_4Ca_3 treatment combinations. On the other hand the minimum plant height (12.19, 16.33, 25.39, 34.25 and 37.37 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (10.75, 20.81, 25.67, 29.81 and 26.75 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (1.82, 4.00, 5.67, 6.00 and 5.42 at 25, 50, 75, 100 DAS and at harvest, respectively), number of pods plant^{-1} (16.65), pod length (2.24 cm), 100 seeds weight (33.18 g), seed yield plot^{-1} (364.00 g), pod yield (1.44 t ha^{-1}), seed yield (0.91 t ha^{-1}), stover yield (2.82 t ha^{-1}), biological yield (4.26 t ha^{-1}), harvest index (33.80%), protein content (29.41%), oil content (32.41%), vitamin E content (4.97 mg 100 g seed^{-1}) and germination (76.60%) were observed from P_1Ca_1 treatment combinations.

CONCLUSION

The results in this research indicated that the variety BARI cheenabadam-10 performed best in respect of pod yield (2.36 t ha^{-1}) and seed yield (1.79 t ha^{-1}) in P_4Ca_3 treatment combination than the other treatment combinations. In case of seed quality parameters, the maximum protein content (39.63%), oil content (48.25%), vitamin E content (9.69 mg 100 g seed^{-1}) and germination (90.70%) were obtained from P_4Ca_3 (32 kg P ha^{-1} with 60 kg Ca ha^{-1}) treatment combinations than the combination of P_1Ca_1 which showed the least performance with protein content (29.41%), oil content (32.41%), vitamin E content (4.97 mg 100 g seed^{-1}) and germination (76.60%). It can be therefore, concluded from the study that the treatment combinations, P_4Ca_3 (groundnut growing on 32 kg P ha^{-1} with 60 kg Ca ha^{-1}) was found to be most suitable combination for the potential pod yield and seed quality of groundnut.

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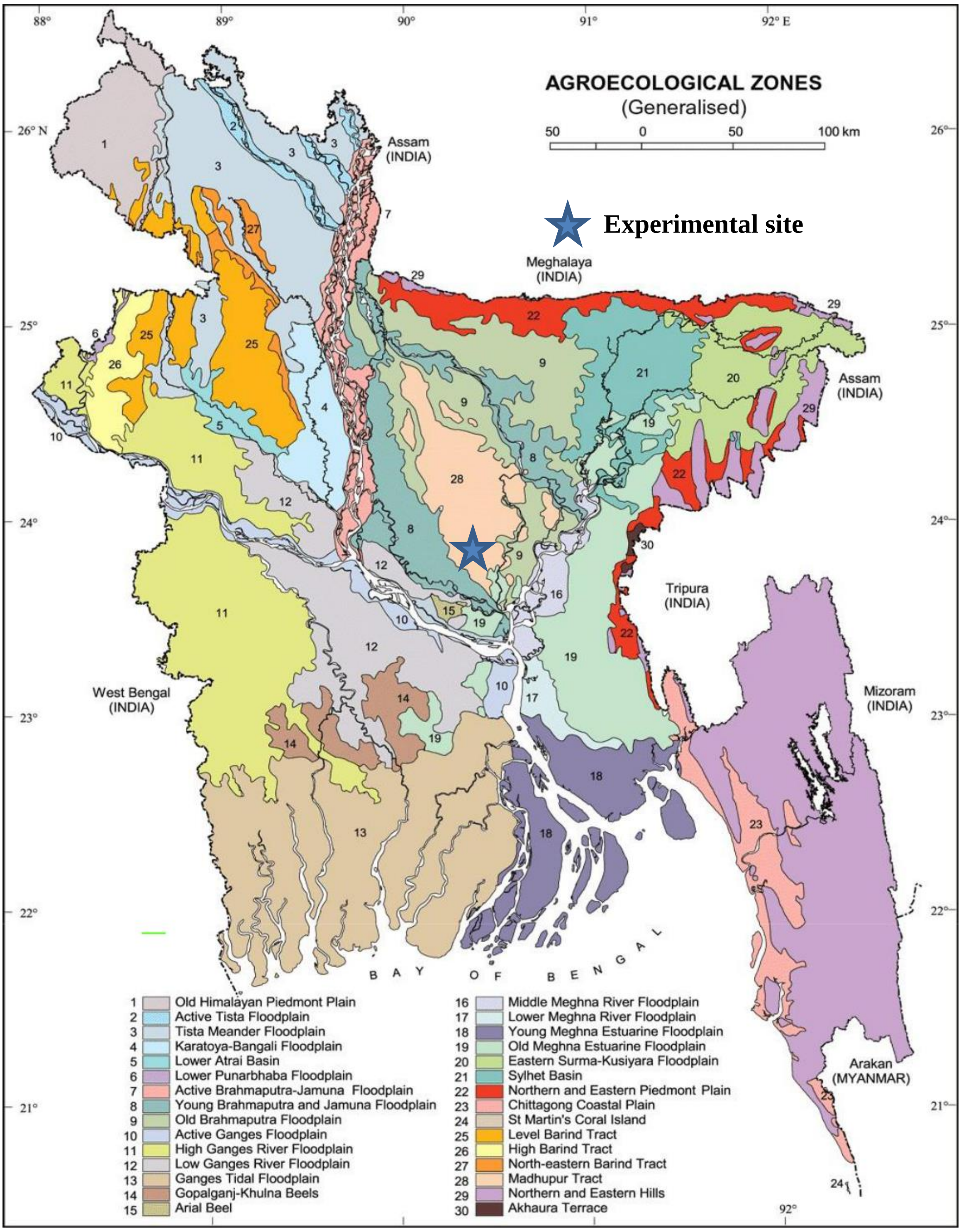
APPENDICES

APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh showing the experimental location



Appendix II. Characteristics of experimental soil analyzed at Soil Resource Development Institute (SRDI), Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Not Applicable

Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

Characteristics	Value
Partical size analysis %Sand	27
%Silt	43
%Clay	30
Textural class	Silty Clay Loam
pH	6.2
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45

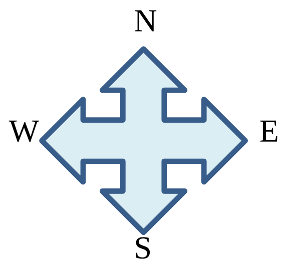
Source: Soil Resource Development Institute (SRDI)

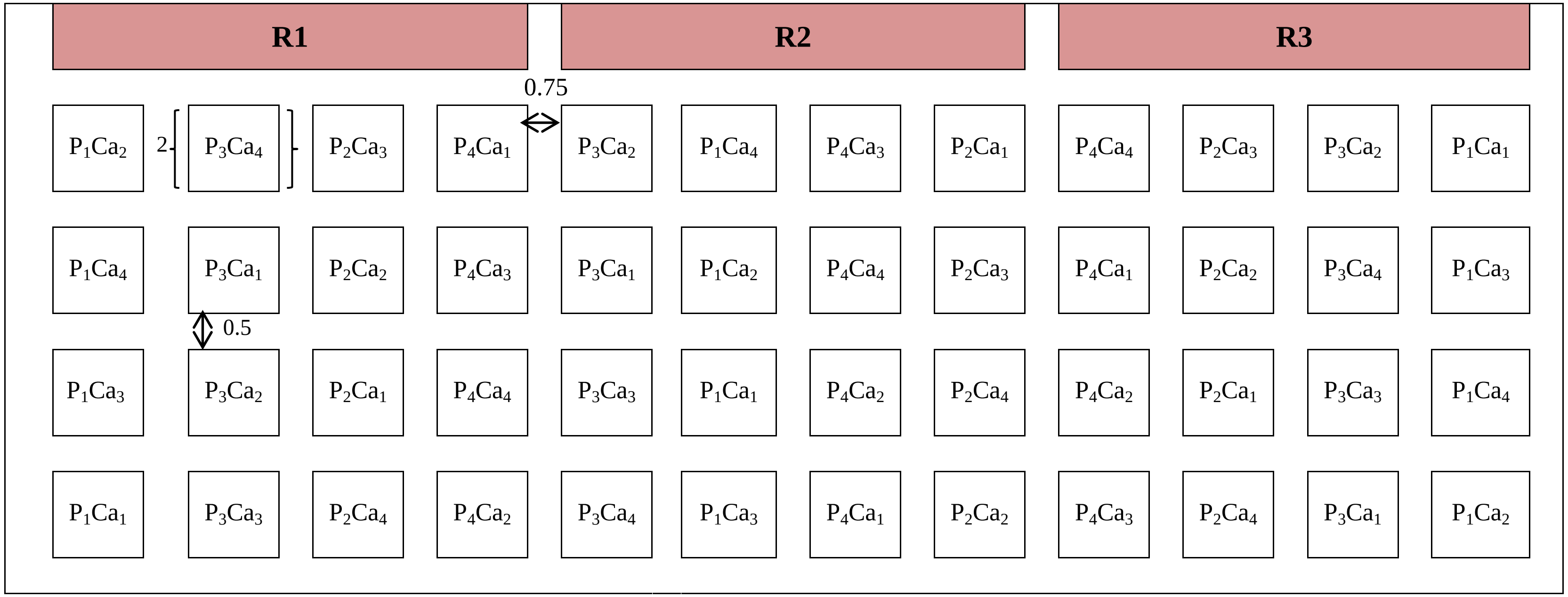
Appendix III. Monthly records of air temperature, relative humidity and total rainfall during the period from April 2021 to August 2021

Year	Month	Air temperature (℃)		Relative humidity (%)	Total rainfall (mm)
		Maximum	Minimum		
2021	April	36.6	21.4	65	86
	May	35.8	24.6	72	92
	June	32.4	25.7	80	86
	July	32.6	26.8	81	114
	August	32.2	26.5	80	106

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1207

Appendix IV. Layout of the experimental plot





Length of plot: 2.00 m, **Width of plot:** 2.00 m

Replication to replication distance: 0.75 m

Plot to plot distance: 0.5 m,

Unit plot size: 2.00 m × 2.00 m (4.00 m^2)

Notes *viz:*

P_1= 0 kg P ha^{-1}
P_2= 29 kg P ha^{-1}
P_3= 32 kg P ha^{-1}
P_4= 35 kg P ha^{-1}

Ca_1= 0 kg Ca ha^{-1}
Ca_2= 55 kg Ca ha^{-1}
Ca_3= 60 g Ca ha^{-1}
Ca_4= 65 kg Ca ha^{-1}

Appendix V. Mean square values of plant height at different days after sowing of groundnut cv. BARI Cheenabadam-10

Sources of variation	Degrees of freedom	Mean square values of plant height at				
		25 DAS	50 DAS	75 DAS	100 DAS	Harvest
Replication	2	10.7912	13.1232	62.4100	90.2500	39.3760
Factor A	3	15.1639**	43.2862**	104.649**	124.235**	116.987**
Error	6	0.7106	0.1216	1.0770	1.5830	0.4940
Factor B	3	6.8249**	15.8422**	32.5620**	51.5080**	45.9700**
A × B	9	0.8973**	0.5999*	1.8010*	3.3450*	2.5000**
Error	24	0.1138	0.3554	0.7430	1.7500	0.7980

* significant at 5% level of significance

** significant at 1% level of significance

Appendix VI. Mean square values of number of leaves plant^{-1} at different days after sowing of groundnut cv. BARI Cheenabadam-10

Sources of variation	Degrees of freedom	Mean square values of number of leaves plant^{-1} at				
		25 DAS	50 DAS	75 DAS	100 DAS	Harvest
Replication	2	4.5263	49.0000	60.0630	100.000	85.5630
Factor A	3	30.3432**	159.440**	311.907**	308.948**	290.557**
Error	6	0.0391	0.6670	0.7290	1.8330	0.2290
Factor B	3	11.8417**	42.1080**	144.881**	154.757**	118.516**
A × B	9	0.5145**	1.3580*	13.3980**	10.2870**	9.2350**
Error	24	0.1682	0.5830	1.0620	1.0420	0.5630

* significant at 5% level of significance

** significant at 1% level of significance

Appendix VII. Mean square values of number of branches plant^{-1} at different days after sowing of groundnut cv. BARI Cheenabadam-10

Sources of variation	Degrees of freedom	Mean square values of number of branches plant^{-1} at				
		25 DAS	50 DAS	75 DAS	100 DAS	Harvest
Replication	2	0.7268	1.1556	1.6002	1.0202	1.0764
Factor A	3	4.6481**	7.3426**	5.4351**	6.8991**	8.9073**
Error	6	0.0262	0.0826	0.0911	0.0055	0.0156
Factor B	3	1.8987**	3.1563**	2.1602**	2.8675**	3.9749**
A × B	9	0.0902**	0.1213**	0.0995*	0.1144**	0.1776**
Error	24	0.0288	0.0378	0.0434	0.0091	0.0220

* significant at 5% level of significance

** significant at 1% level of significance

Appendix VIII. Mean square values of number of pods plant^{-1}, length of pod, weight of 100 seeds and seed yield plot^{-1} of groundnut cv. BARI Cheenabadam-10

Sources of variation	Degrees of freedom	Mean square values of			
		Number of pods plant^{-1}	Length of pod	Weight of 100-seed	Seed yield plot^{-1}
Replication	2	44.8900	0.0371	85.7010	10252.00
Factor A	3	51.5718**	0.2254**	223.2820**	1302515.00**
Error	6	0.2317	0.0040	1.1150	885.00
Factor B	3	20.1430**	0.0797**	97.1040**	56627.00**
A × B	9	0.9285*	0.0048*	2.9440**	4502.00**
Error	24	0.4796	0.0032	0.6810	1018.00

* significant at 5% level of significance

** significant at 1% level of significance

Appendix IX. Mean square values of pod yield, seed yield, stover yield, biological yield and harvest index of groundnut cv. BARI Cheenabadam-10

Sources of variation	Degrees of freedom	Mean square values of				
		Pod yield	Seed yield	Stover yield	Biological yield	Harvest index
Replication	2	0.0756	0.0576	0.2209	0.5929	75.4292
Factor A	3	0.8370**	0.8157**	0.4467**	2.5062**	45.3449**
Error	6	0.0025	0.0070	0.0056	0.0233	0.8259
Factor B	3	0.3422**	0.3539**	0.2146**	1.0986**	14.6424**
A × B	9	0.0314**	0.0281**	0.0122*	0.0820**	1.4099*
Error	24	0.0041	0.0067	0.0049	0.0132	0.5701

* significant at 5% level of significance

** significant at 1% level of significance

Appendix X. Mean square values of protein content, oil content, vitamin E content and germination percentage of groundnut cv. BARI Cheenabadam-10

Sources of variation	Degrees of freedom	Mean square values of			
		Protein content	Oil content	Vitamin E content	Germination percentage
Replication	2	48.6506	82.0380	2.2877	248.0630
Factor A	3	92.8494**	243.5350**	23.3575**	165.2720**
Error	6	0.5446	0.3790	0.1496	0.7290
Factor B	3	37.3709**	109.7930**	8.4625**	75.6730**
A × B	9	1.6010*	7.6910**	0.5266*	3.7440*
Error	24	0.5355	1.2180	0.2060	1.5620

* significant at 5% level of significance

** significant at 1% level of significance