EFFECT OF CALCIUM AND BORON ON YIELD AND SEED QUALITY OF GROUNDNUT

A Thesis

By

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*This is to certify that the thesis entitled "**Effect of Calcium and Boron On Yield and Seed Quality of Groundnut**" submitted to the **Institute of Seed Technology**, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the Degree of **Master of Science** in **SEED TECHNOLOGY**, embodies the result of a piece of bona fide research work carried out by **ANIKA NAWER**, Registration no.**15-06660** 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.

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DEDICATED TO

MY

BELOVED PARENTS

DECLARATION

I declare that the thesis hereby submitted by me for the MS degree at the Sher-e-Bangla Agricultural University is my own independent work and has not previously been submitted by me at another university/ faculty for any degree.

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The Author

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ABSTRACT

A gradual decline in groundnut yield has been reportedly subjected to various agro-climatic conditions and soil fertility problems. Proper application of Ca and B may improve yield and seed quality of groundnut. The experiment was conducted at the Research Field of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, during the period of March to July, 2021 to study the response of different levels of calcium and boron application on groundnut yield and seed quality. BARI Chinabadam-10 was used as test crop in this experiment. Experiment was carried out in Split-plot design and consisted of two factors. Four levels of calcium *viz.*, Ca_1= 0 kg Ca ha^{-1} (0 kg gypsum ha^{-1}) (control), Ca_2= 50 kg Ca ha^{-1} (250 kg gypsum ha^{-1}), Ca_3= 60 kg Ca ha^{-1} (300 kg gypsum ha^{-1}) and Ca_4= 70 kg Ca ha^{-1} (350 kg gypsum ha^{-1}) and four levels of boron *viz.*, B_1= 0 kg B ha^{-1} (0 kg boric acid ha^{-1}) (control), B_2= 1.275 kg B ha^{-1} (7.50 kg boric acid ha^{-1}), B_3= 1.7 kg B ha^{-1} (10 kg boric acid ha^{-1}) and B_4= 2.125 kg B ha^{-1} (12.50 kg boric acid ha^{-1}). Calcium and boron levels were revealed to have a significant influence on groundnut yield and seed quality. The study results revealed that yield and quality parameters gradually increased with increasing Ca and B level upto Ca_3 (60 kg Ca ha^{-1}) and B_3 (1.7 kg B ha^{-1}) levels and thereafter slightly decreased, although maintain statistical similar results. In case of 16 treatment combinations, the treatment with 60 kg Ca ha^{-1} + 1.7 kg B ha^{-1} (Ca_3B_3) recorded significantly higher number of pods palnt^{-1} (23.53), pod length (2.71 cm), 100-seeds weight (46.92 g), seed yield (2.35 t ha^{-1}), stover yield (3.37 t ha^{-1}), biological yield (5.72 t ha^{-1}), harvest index (41.08 %), germination percentage (90.50 %), protein content (38.72 %), oil content (47.90 %), vitamin E content (9.68 mg/100g seed) compared to all other treatment combinations. The present study concludes that maximum yield and seed quality of groundnut could be achieved by applying of 60 kg Ca ha^{-1} (300 kg gypsum ha^{-1}) and 1.7 kg B ha^{-1} (10 kg boric acid ha^{-1}).

LIST OF CONTENTS

(Continued)

LIST OF CONTENTS (Continued)

(Continued)

LIST OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

(Continued)

LIST OF FIGURES (Cont'd)

LIST OF APPENDICES

LIST OF PLATES

LIST OF ACRONYMS

Acronym		Full meanings
AEZ	=	Agro-Ecological Zone
%	=	Percent
^0C	=	Degree Celsius
BARI	=	Bangladesh Agricultural Research Institute
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

Bangladesh is a country that is populated, rural, and agrarian, and where agriculture, which comprises the subsectors of crops, fisheries, livestock, and forestry, continues to be the main economic sector (Rahman *et al*., 2017). Agriculture has a significant role in the nation's economy. A majority of Bangladesh's population relies on agriculture, either directly or indirectly, for a living. Of the nation's Gross Domestic Product (GDP), agriculture contributes significantly (11.63%) (MOA, 2022). Current figures show that the nation consumes 3.03 million tons of oils and fats annually (BBS, 2021). Bangladesh barely produces roughly 40% of its domestic oil needs (Mouri *et al*., 2018). In the 2019–20 fiscal years, Bangladesh imported 2.77 million tons of edible oils, fats, and oil seed for $2.12 billion (BBS, 2021). Because groundnut contains more oil than other oil seeds produced in Bangladesh, boosting groundnut production can be an excellent choice for edible oil.

In Bangladesh, groundnut is primarily grown on marginal land in the summer and winter (Jahan *et al*., 2022). Over the past ten years, both its area and productivity have progressively decreased. It is the third-most important oilseed crop in Bangladesh (BBS 2022). Groundnut cultivation covered around 40267.84 hectares, and production was about 74748.67 tons during the cropping season of 2020–2021 (BBS, 2022). It occupies only about 6.97% of the total area under all oil crops and contributes about 6.73% to the total oilseed production in 2020- 2021 (BBS, 2021). The soil and climate of Bangladesh are quite suitable for groundnut production. It is cultivated mostly in sandy soils and riverbeds (Nath and Alam, 2002). Although being one of Bangladesh's main oilseed crops, groundnuts provide lower yields (1.86 t ha^{-1}) compared to the global average (Jahan *et al*., 2022). The low productivity of groundnuts is a result of low levels of organic matter in the soil, poor soil fertility, and uneven use of mineral fertilizers without organic additions (Akbari *et al*., 2011).

Being a leguminous crop, groundnut can fix atmospheric nitrogen through symbiotic nitrogen-fixing bacteria in root nodules, requiring less nitrogen-containing fertilizers. It also improves nitrogen content in the soil, making this plant beneficial in crop rotation (Haneena *et al*., 2021). Groundnut being an oilseed crop and considered as heavy feeder of nutrients (Shete *et al*., 2018). An average crop of groundnut yielding 19 q ha^{-1} removes about 170 kg N, 30 kg P, 110 kg K, 39 kg Ca and 15 kg S from the soil (Aulakh *et al*., 1985). Thus, growing groundnuts rapidly depletes the soil's fertility unless the crop is properly fertilized. One of the main factors limiting the production of groundnuts is a lack of secondary and micronutrients (Mansingh *et al*., 2022). The highest secondary nutrient needs are for oil seed crops. Groundnut requires essential nutrients for its growth and development at various stages of growth. Among these, calcium and boron are essential.

One of the significant mineral components found in soil is calcium, which is vital for numerous biochemical and metabolic activities (Kadirimangalam *et al*., 2022). Groundnut has a distinct fruiting behavior that plays a vibrant role in the intake of minerals particularly Ca (Jahanzaib *et al*., 2020). One of the least mobile minerals in plants is calcium (Mavimbela *et al*., 2021). There is not much transfer from the main plant components into the developing pods in groundnut (Zharare *et al*., 1998). Ca cannot effectively flow through phloem tissues; instead, it moves from roots to shoots in the transpiration stream via xylem (Jahanzaib *et al*., 2021). Because groundnut pods grow underground, they cannot absorb and exhale calcium from the plant, so the pods must obtain it directly from the earth (Sumner *et al*., 1988). Ca is a crucial component for pegging, pod formation, and pod filling. For somewhat acidic soils to achieve the proper pH and improve the quality of the seed, calcium must be applied (Mavimbela *et al*., 2021). Poor peanut seed germination and disease susceptibility are caused by calcium shortage, which also affects yield and quality (Gascho and Davis. 1994). Lack of accessible Ca results in embryo abortion, which significantly lowers production (Csinos and Gaines, 1986). It also reduces the quantity of sound mature kernels in the peanut. Also, it has been demonstrated that a lack reduces the quality of the seed by preventing the development of peanut plumules (Sullivan *et al*., 1974). The number of locules that were filled and the percentage of shelling were found to be positively correlated by Hartmond *et al*., (1994), who also established that a low percentage of shelling is a sign of calcium insufficiency. Calcium in the soil in the proper amounts helps prevent black hallow, reduces the generation of aflatoxin, and prevents decaying and split peanut pods (Habib, 2014). Because it is necessary for plumule growth, calcium has a direct relationship to seed quality (Harris and Brolmann, 1966). Kamara *et al.* (2011) reported significantly higher number of filled pods, shelling percentage and hundred seed weight and higher pod yield with the application of 100 kg Ca ha^{-1} than the control. When gypsum was applied to low-calcium soil, Walker and Keisling (1978) noticed a percentage rise in the oil content. Gypsum (240 kg Ca ha^{-1}) was applied to plants during the flowering stage, which results in more nodules per plant, more protein, and more oil (Ursal *et al*., 1994). By increasing the application of gypsum from 0 to 400 kg ha^{-1}, there is a noticeable rise in the amount of oil produced per hectare (Adhikari *et al*., 2003). Rahman (2006) determined that as the calcium application amount increased from 0 to 100 kg ha^{-1}, there was an upward trend in qualitative features like the oil percentage and protein percentage.

Boron (B) is an important micronutrient required for normal plant growth and obtaining high quality crop yields (Murmu *et al*., 2014). It appears to be essential for the preservation of structural integrity and for shielding the plasma membranes from peridoxidative damage (Ismail and Volkar, 1997). According to Parr and Loughmann (1983), B is involved in sugar transport, the synthesis of cell walls, lignifications, the production of Indole Acetic Acid (IAA), and phenol metabolism. It is crucial for the physiological processes of plants, including protein synthesis, meristematic tissue development, cell elongation, and cell maturation (Mengel and Kirkby, 1982). Increase in protein content with the application of B has been reported by Mahendran *et al.,* (2*015)* in groundnut and Sarker *et al.,* (2002) in soybean. According to Haneena *et al.* (2021), boron is essential for the development of legume nodules and for the plants' ability to fix nitrogen (Hanumanthappa *et al*., 2019). Boron aids in improved root establishment, which improves nutrient uptake and metabolism. B treatment also facilitates groundnut's uptake of N and raises plant height, dry weight, and overall number of pods (Jing *et al*., 1994). Thus, under deficiency symptoms, plants exhibit dwarfism, rolling, cracking, and dying growth points, as well as poor seed germination (Poonguzhali and Pandian, 2018). Alloway (2008) indicated that boron is found in relatively high concentration in chloroplasts. Before any signs of a boron deficit are noticeable, the chloroplasts degenerate and the cell wall go through significant structural alterations. According to Kaisher *et al.* (2010), the application of boron may have increased the plant height of the groundnut crop. This growth may be attributed to soil and foliar applications of B, which may regulate metabolic processes and enzymatic processes like photosynthesis, respiration, and symbiotic N-fixation.

Although boron is a crucial ingredient for plants, it has the narrowest range between deficiency and toxicity of any other element (Goldberg, 1997). The highest groundnut pod protein content was recorded at 1.0 ppm and further increase in B levels the protein content get decreased correspondingly (Muthukrishnan, 2007). Kundu *et al.* (2016) reported that in black calcareous soil, the soil application of 5.8 kg ha^{-1} boric acid increased the yield and in sandy soils 0.5-1.0 kg ha^{-1} boron is sufficient. Boron (B) deficiency problem for crop production have been identified in Bangladesh (Ahmed and Hossain, 1997) and application of boron in crops is limited at farmer's field (Nasreen *et al*., 2015). Even farmers are unaware of how crucial boron is for groundnut (Quamruzzaman, 2015). Unfortunately, little to no research was done in Bangladesh to determine how calcium and boron affected groundnut output and seed quality. For better growth, reproductive development, production, and quality of groundnut, it is crucial to understand how calcium and boron affect yield and seed quality.

The following objectives were set for the present study with all the aforementioned considerations in mind:

1. To determine the optimum level of calcium and boron for maximizing yield and seed quality of groundnut.
2. To find out the suitable combination of calcium and boron on yield and seed quality of groundnut.

CHAPTER II

REVIEW OF LITERATURE

3.1. Calcium

Calcium is a necessary ingredient for the correct growth of groundnut or peanut (*Arachis hypogea* L.), and it is crucial for the formation of cell walls (Marschner, 1995), unfilled pods (Smith, 1954), darker seed plumules (Cox and Reid, 1964), and decreased germination (Harris and Brolmann, 1966) can all be caused by insufficient Ca uptake during development. Ca additions can lower the frequency of aborted seed, hence boosting groundnut output and grade. Unfilled pods, or pops, can significantly reduce yield and grade. Seed plumules are crucial for germination, and damage from a lack of calcium can sharply lower germination rates (Adams *et al*., 1993). Groundnuts grown for their seeds have greater calcium needs, and studies have shown that adding calcium to the soil can enhance seed calcium levels and improve germination without affecting yield or quality (Tillman *et al.*, 2010).

3.1.1. Calcium uptake and availability

Ca is absorbed by roots and transferred to transpiring tissues through the xylem during vegetative growth. Ca is no longer provided to the growing pod from the above ground plant section once pegs enter the soil during reproductive growth and transpiration stops (Skelton and Shear, 1971). Instead, pods use passive diffusion to take up Ca straight from the soil solution (Sumner *et al.*, 1988). Throughout reproductive growth, calcium is absorbed; with the maximum rates occurring in the first 20 to 30 days after the peg is inserted into the soil (Mizuno, 1959). Plants are approaching peak pod fill during the 20 to 30 day window, and appropriate soil Ca and water content are essential for maximum yield (Stansell *et al.*, 1976). Due to passive diffusion by developing pods, the Ca percentage in soil solution rather than on exchange sites forms the Ca available for reproductive growth; hence, availability is influenced by soil Ca levels in addition to soil water content (Cox *et al.*, 1982). In Bangladesh, Ca, Mg, and K concentrations are significantly below ideal levels, and in certain circumstances, even below critical limits (Biswas *et al.*, 2019). About 2,106,053 hectares, or 24.53% of Bangladesh's arable land, have very low to low calcium content in loamy to clayey soils in 2020, which is more than seven times the estimated 300,000 hectares in 2010. (Islam and Hasan, 2015). About 1,311,470 hectares, or 15.27% of the arable land, have a medium calcium level. The proportion of arable lands with calcium content that is optimal and high to very high is 11.81% and 48.39%, respectively (Hasan *et al.*, 2020). Soil productivity reduces 50-75% if soil calcium content is ≤ 1.125 meq/100g of soil and 25-50% if soil calcium is between 1.126-3.0 meq/100g of soil (Zahid *et al*., 2020).

3.1.2. Calcium source

High levels of Ca that are readily available throughout the growing season are necessary for proper seed development. Due to their capacity to provide sufficient Ca to groundnuts throughout reproductive growth, lime and gypsum are the most often utilized Ca supplements for peanut production (Hartzog and Adams, 1988). Producers may benefit from calcium supplies that increase application efficiency, such as humate-containing fertilizers or liquid suspensions. Gypsum is a very soluble calcium supplement (calcium sulfate, $CaSO_4$) that has no affect on pH. For this reason, when pH levels are appropriate, gypsum is substituted for lime. Gypsum is particularly vulnerable to leaching from the pegging zone because to its solubility; therefore, it is crucial to time gypsum applications to provide sufficient soil calcium for pod growth throughout the growing season (Daughtry and Cox, 1974).

3.1.3. Response of calcium on yield and seed quality

Aruna *et al.* (2022) carried out an experiment to investigate the effect of zinc and gypsum on growth and yield of Groundnut (*Arachis hypogaea* L.)" conducted during *kharif*, (2021) at crop research farm, Department of Agronomy, SHUATS, Prayagraj (U. P) on sandy loam soil. The significantly highest result showed in (0.75% zinc foliar spray + 500 kg ha^{-1} Gypsum) growth and yield attributing character *viz*., plant height (58.33 cm), nodules $plant^{-1}$ (106.88), dry weight (39.3 g), pod $plant^{-1}$ (19.3), kernel pod^{-1} (2.6), seed index (41.00), seed yield (2917.00 kg ha^{-1}), haulm yield (4453.3 kg ha^{-1}).

Inban *et al.* (2022) carried out an experiment to find out the effects of calcium sources on physiological traits related to pod and seed yield of peanut. They reported that calcium sources were significantly different for crop growth rate (CGR), pod growth rate (PGR), total dry matter at 65 and 92 DAP, and seed yield at harvest.

Vaishnav *et al.* (2022) conducted an field experiment entitled "Growth and development of groundnut (*Arachis hypogaea* L.) as influenced by different levels and timing of phosphogypsum nutrition" was planned to ascertain the role of phosphogypsum an industrial by product in promoting growth of groundnut. Among different treatments, application of phosphogypsum 125 kg S eq ha^{-1} in split recorded highest growth parameters like plant height (42.49 cm), leaf area (1137 cm^2 plant^{-1}), dry matter per plant (29.30 g) and number of branches plant^{-1} (8.62). Whereas, application of phosphogypsum 100 kg S eq ha^{-1} in split found on par with 125 kg with respect to all growth parameters. While lowest values of all the parameters were noticed in treatment receiving N and K fertilizer alone.

Haneena *et al*. (2021) carried out an experiment to study the effect of boron on quality parameters and micronutrient uptake of groundnut in coastal sandy soils. Experiment results concluded that Protein content, boron content and uptake of micronutrients viz., iron, zinc, manganese, copper and boron were significantly improved with the application of boron in groundnut. Oil content and oil yield were not significantly influenced by the application of boron. The highest value of all these parameters were recorded in T_4 (RDF + soil application of Borax @ 12.5 kg ha^{-1}).

Jahanzaib *et al*. (2020) carried out an experiment to evaluate the effect of temporal application of gypsum on mineral uptake and economically important morphometric traits in groundnut (*Arachis hypogea* L) under rain-fed conditions. Five different treatments were applied in two split doses i.e. T_1 (0 %:100 %), T_2 (25 %:75 %), T_3 (50 %:50 %), T_4 (75 %:25 %), and T_5 (100 %:0 %) at the time of sowing and pegging compared with Check (T_0 The highest pod yield (3522.2 kg ha^{-1}), root biomass (9.03g plant^{-1}), and nodules (382 plant^{-1}) were observed in treatment T_3. The calcium concentration (0.80 %) in shoots of T_3 was the highest.

Liu *et al.* (2021) investigated the effects of sorbitol calcium chelate on peanut, with the goal of promoting peanut yield and improving the utilization of calcium fertilizer. Field experiments were carried out in Jimo, Shandong Province, China. Compared with the corresponding sorbitol non-chelated calcium fertilizer treatments, the yield of peanuts increased by 10.0 and 1.7% under sorbitol chelated calcium concentrations of 1.6 and 2.4 g L^{-1}, respectively, besides, the calcium and potassium contents of the seed kernel increased by 32.2 and 55.8%, under sorbitol chelated calcium concentrations of 1.60 and 2.40 g L^{-1}, respectively. Sorbitol calcium chelate improved peanut yield and promoted the transformation of sugars to fat in the seed kernel, the 1.6 g L^{-1} concentration produced the best results. Compared with the blank control, the 1.60 g L^{-1} sorbitol chelated calcium fertilizer treatment increased peanut yield by 28.6%, fruit number per plant by 46.8%, 100-kernel weight by 20.4%, full fruit number per plant by 55.3%, fat content by 5.0%.

Rajanarasimha *et al.* (2021) executed 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. Results were revealed that maximum number of Plant height (73.56), 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 gm) 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 45kg ha^{-1} + Calcium 60kg ha^{-1} in plant height (73.56 cm), kernel yield (2.17 t ha^{-1}) and Haulm Yield. (5.60) harvest index (36.40%) was recorded. Therefore, I 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.

Ransing *et al.* (2021) conducted a field experiment to evaluate the effect of gypsum and phosphogypsum application on micronutrient status of soil under summer groundnut. During both the years, the DTPA extractable Fe, Mn, Zn and Cu was significantly higher with the application of RDF (S free) along with phosphogypsum @ 400 kg ha^{-1} at 45, 70, 95 DAS and at harvest. However, the micronutrients content was statistically on par with RDF (S free) with soil application of phosphogypsum @ 300 kg ha^{-1} at 45 DAS. With regard to available boron content, slight decline was noted with an advancement of growth stage of groundnut. The available boron in root zone of groundnut was found significantly higher with RDF (S free) with the application of phosphogypsum @ 200, 300 and 400 kg ha^{-1} (0.40 mg kg^{-1}) at 70 DAS.

Aier and Nongmaithem (2020) reported that application of lime @ 3 t ha^{-1} gave significant variation in number of pods $plant^{-1}$, kernel yield (kg ha^{-1}), stover yield (kg ha^{-1}) and harvest index (%) with the application of lime. They are reported that the highest pods plant^{-1} (30.87), kernel yield (1398.14 kg ha^{-1}), stover yield (2865.29 kg ha^{-1}) and harvest index (39.17%) was recorded when lime was applied @ 3 t ha^{-1}.

Sagar *et al.* (2020) conducted an experiment to study the effect of phosphorus and gypsum on growth, yield and economics of ghroundnut (Arachis hypogea L.) and reported that 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}.

Ullah *et al.* (2019) conducted an experiment to investigate the effect of gypsum application on groundnut growth and nodules under rainfed condition. They reported that root length of ground nut plant was significantly differed among gypsum treatments, 50% gypsum requirement application showed maximum root length. 25%, 50%, and 75% gypsum application regarding shoot length presented statistically at par with each other but gypsum application showed better shoot length than without gypsum. The highest root biomass (9.2 gm) was received by 50% gypsum that was statistically at par with the root biomass of 100% gypsum. Maximum shoot biomass was gained with 50% gypsum applied treatment. Gypsum application increased number of leaves per plant. 50% gypsum treated plants attained the highest number of nodules that was statistically at par with 25% gypsum treated plants. 75 and 100% gypsum applied plants depicted statistically same findings with one another but were higher nodule number than control. The effect of gypsum on nitrogen and protein contents of groundnut straw and nut was directly proportional to gypsum dose. These contents were improved as well as the gypsum percentage increased. Increase over control in nitrogen contents and protein was the top (6.9%) in 100% gypsum. Similar trend was also noted in groundnut nut nitrogen and protein.

Kamara *et al.* (2017) investigated the effect of calcium and phosphorus fertilizer on seed quality, oil and protein content of two groundnut varieties in two laboratory experiments. The results showed that increased calcium fertilization increased the vigour, germination and oil content of the seeds of the two groundnut genotypes. They also reported that the treatment with 100 kg Ca ha^{-1} gave the highest seed yield (2232.6 and 1892.1 kg ha^{-1}) of Nkosour and Shitaochi respectively whilst the control (Shitaochi) had the lowest seed (1133.2 kg ha^{-1}) in the Major season. However, no significant difference was obseved between the 100 kg Ca ha^{-1} and 200 kg Ca ha^{-1} fertilizer applications in the two groundnut varieties in both seasons.

Das *et al.* (2016) concluded that liming significantly increased plant height, leaf area index, dry matter production, nodule weight and counts/plant than no liming. Application of micronutrients and liming also improved crop growth rate and relative growth rates of plant. Furrow liming also enhanced the kernel yield (1756 kg ha^{-1}) significantly than that of no liming (1511 kg ha^{-1})

Sikhakhana (2016) conducted two field experiments to study the effect of calcium source (gypsum) fertilizer application on yield and quality of groundnut (*Arachis hypogaea* L.). Results concluded that the application of gypsum at 1000 kg ha^{-1} and lime at 500 kg ha^{-1} respectively, significantly improved peanut yield and soil pH. The combination of gypsum and lime (500 kg ha^{-1} gypsum and 250 kg ha^{-1} lime) significantly improved shelling percentage (yield).

Das *et al.* (2015) designed a farm Trial to increase yield and quality of ground nut seed by application of recommended fertilizers along with some micro-nutrients for consecutive four years as the soil is deficient of micro-nutrients like Ca and S, which essential for ground nut production. It was found that Var. TG51 gave maximum yield, when the crop was supplied with NPK (20-60-40 kg ha^{-1}) in the form of Straight fertilizer Urea, SSP, MOP + 200 kg Gypsum during 30 DAS + 15 kg Sulphur during pegging and regarding quality improvement on oil content was improved by application of sulphur 25kg ha^{-1}. Seed germination was improved by application of recommended doses of NPK (20-60-40 kg ha^{-1}) in the form of composite fertilizer IFFCO-10:26:26 + 400 kg Gypsum ha^{-1} in two split doses @ 200 kg at 30 days after sowing and at the time of Flowering.

Yadav *et al.* (2015) carried out an experiment during *kharif* season of 2010 to study the effect of different levels of added gypsum (0, 100, 200, 300 and 400 kg ha^{-1}) with RDF (NPK @ 25:50:20 kg ha^{-1}) on growth and yield of Groundnut (*Arachis hypogaea* L.). The results indicated that effect of different levels of gypsum had significant effect on growth and yield of groundnut. Biological growth and yield attributes viz., plant height, number of branches $plant^{-1}$, number peg, number of nodules, fresh weight of pod, dry weight (pod yield), straw yield were also significantly affected by the application of different levels of gypsum. The highest plant height and number of branches plant^{-1} at 90 DAS (23.16 cm and 9.80, respectively), number of peg and number of nodules at 90 DAS (22 and 122, respectively), fresh weight of pod and dry weight (pod yield) (37.88 and 26.10 q ha^{-1}, respectively) and straw yield (37.97 q ha^{-1}) were found by the application of NPK-25:50:20 kg ha^{-1}+ gypsum @ 200 kg ha^{-1}.

Arnold (2014) emphasizes that low calcium levels in soils can reduce peanut yield, grade, and seed quality.

Habib (2014) conducted a field experiment to study the influence of application of Ca fertilizer (Gypsum) at optimum level on peg and pod development of groundnut varieties. he experiment was carried out in split plot design considering three varieties *i.e.* BARI Chinabadam-8, BARI Chinabadam-9 and Dhaka-1(Maijchaur badam) in the main plot and five levels of Ca (calcium) *viz.* NPKCa + No split application of Ca, NPK + 100 kg Ca ha^{-1} at flower initiation (45 DAS), NPK + 200 kg Ca ha^{-1} at flower initiation (45 DAS), NPK + 300 kg Ca ha^{-1} at flower initiation (45 DAS) and NPK + 400 kg Ca ha-1 at flower initiation (45 DAS) in the sub plot replicated three times. BARI Chinabadam-8 gave highest pod yield (1.85 t ha^{-1}) which was 16.35 % and 8.19% higher than the Dhaka-1 (1.59 t ha^{-1}) and BARI Chinabadam-9 (1.71 t ha-1), respectively. The highest protein content (34.13 %) was recorded from the combination BARI Chinabadam-8 with NPK + 100 kg Ca ha^{-1} at flower initiation (45 DAS) while lowest one was recorded from treatment combination BARI Chinabadam-9 with NPK + 400 kg Ca ha^{-1} at flower initiation (45 DAS) producing 30.15 %.

Hassan and Mahmoud (2014) to investigated the effect of different sources of calcium, organic and inorganic nitrogen on sandy soil, peanut yield and components and found that the values of pod dry weights was increased from 630.0 to 4800.0 kg fed^{-1} as mean values in the control treatment for the label zeolite at different calcium resources, respectively. They also reported that the values of pod dry weight were increased from 630.0 to 3444.0 kg fed^{-1} for the organic compost at different calcium resources.

Thilakarathna *et al.* (2014) conducted a field experiment to find out the effect of gypsum on the yield and quality of groundnut in Maspotha divisional secretariat area in the Kurunegala district. The results revealed that the application of 250 kg ha^{-1} of gypsum changed the soil pH from 4.1 to 5.0 and increased the mean pod dry weight from 618 to 865 g with high quality kernels (with good appearance and size).

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 per 25 plants^{-1} (202).

Gashti *et al.* (2012) carried out and experiment to investigate the effect of calcium and potassium application on yield and yield components of peanut (*Arachis hypogaea* L.). Results showed that the application of calcium had significant effect on pod yield, kernel yield and oil content, so that applying of 90 kg ha^{-1} calcium from gypsum performed considerably better than the rest. But applying of these fertilizers had no significant effect on protein content of peanut kernel. The yield of pod and kernel also increased with increasing of calcium application along with potassium. The highest yield of pod (5650 kg ha^{-1}) and kernel (4622 kg ha^{-1}) were obtained from 90 kg calcium form of gypsum. The highest oil content (46.22%) was obtained in 90 kg calcium and 30 kg potassium (interaction effect).

Kamara *et al.* (2011) conducted two experiments were at the CSIR-Crops Research Institute (CSIR-CRI), Kumasi in Ghana during the major and minor seasons of 2009 to study the effects of calcium and phosphorus fertilization on the growth and seed yield of groundnut (*Arachis hypogaea* L.). Results concluded that application of calcium fertilizer had a positive effect on the number of filled pods, shelling percentage and 100 seed weight. Application of 100 kg Ca ha^{-1} significantly ($P \leq 0.05$) out-yielded the control in number of filled pods, shelling percentage and 100 seed weight, which invariably resulted in higher pod and seed yields.

3.2. Boron

Since its insufficiency affects more crops and acreage than that of any other micronutrient, boron is a crucial micronutrient for most crops (Gupta, 1993). The development and durability of cell walls, the preservation of the structural and functional integrity of biological membranes, the transfer of sugar or energy into plant developing sections, pollination, and seed set are just a few of the many tasks that boron is essential for in plants (Hasan *et al.*, 2020). B is also necessary for legume crops to effectively fix nitrogen and nodulate (Bolanos, 2004). Inadequate B impairs the strength and porosity of cell walls and prevents the formation of reproductive organs (Camacho-Cristóbal *et al.*, 2008). Due to the role that boron plays in the formation of flowers and seeds, boron requirements during reproductive growth are higher than those during vegetative growth, and a sufficient boron supply throughout the reproductive growth period is essential (Mozafar, 1993). Boron shortage in groundnut causes "hollow heart," or internal kernel damage, as a result of the cotyledons' deformation and discoloration (Harris and Gilman, 1957). Moreover, plant internodes are also shortened, branches are cracked, and flowering time is prolonged (Benton, 2016). Damaged kernels significantly lower the quality and value of the crop (Gascho and Davis, 1995). Increased damaged kernel (DK) content has an impact on quality, and if the DK content exceeds 2.5%, the value could be reduced by 65% (Benton, 2016).

3.2.1. Boron uptake and availability

The management of boron in groundnuts may be considerably impacted by the fact that boron is very mobile in the soil but has limited mobility in plants (Benton, 2016). Due to its water solubility and ease of leaching by strong rains, boron is less readily available in sandy soils with low pH and organic matter (Goldberg, 1997). Boron shortage is most common in humid, coarse-textured soils. Reduced B availability to the plants is also a result of liming, high N-P-K fertilization, and dry weather. Boron is absorbed by plants in its undissociated, neutral form when soil pH is in the ideal range for plant growth (Marschner, 1995). Via both active and passive mechanisms, plants absorb B from the soil solution (Stangoulis *et al.*, 2001). With just a small amount of redistribution through phloem tissues, B is largely delivered by the xylem (Raven, 1980). B translocation to the seed, however, is likely to occur via phloem tissues rather than xylem tissues (Campbell *et al.*, 1975) because pods form below ground and transpiration is negligible (Moctezuma, 1999). In Bangladesh, optimum soil boron content decreases from 16.07% to 15.90% and high to very high soil boron content decreases from 37.04% to 25.95% from 2010 to 2020, very low to low soil boron content in loamy to clayey soils was 25.99% in 2010 and increased to 30.78%

in 2020, medium soil boron content was 20.90% in 2010 and increased to 27.37% in 2020 (Hasan, 2020). If soil boron content is less than 0.15 ppm and between 0.15 and 0.30 ppm, soil productivity is reduced by 50–75% and 25–50%, respectively (Zahid *et al.*, 2020).

3.2.2. Boron source

Boron requirements are high during reproductive growth, since B plays a significant role B in flowering and seed development (Mozafar, 1993). In particular, sufficient B is critical during the early stages of groundnut reproductive growth (30-35 days after planting, DAP). Boron is commonly soil or foliar applied as boric acid or sodium borate (Cleave, 2019). Boric acid products and Solubor are water-soluble and often foliar applied (Mortvedt and Woodruff, 1993).

3.2.3. Response of boron on yield and seed quality

Khuong *et al.* (2022) conducted a field experiment to determine the optimal concentration of boron (B) to obtain the highest growth, yield, and oil content of black sesame. Results showed that spraying B on leaves increased sesame growth in terms of plant height, number of leaves, and chlorophyll content. Moreover, spraying B increased yield components including the number of pods; the highest pods per plant was 46.2 in the B application treatment with 150 mg L^{-1} compared to the control with 27.2 pods per plant. The grain yield of the B spray treatment produced 1.10–1.32 t ha^{-1}, with the highest yield at the dose of 150 mg L^{-1} and the lowest yield at no B spray treatment. Spraying B on leaves at optimal concentration also increased the oil content in seeds up to 5.3% compared to the control treatment. The findings of the study suggest that foliar B application with 150 mg L^{-1} increases the growth, fruit set, seed yield, and oil content in sesame.

Hossain *et al*. (2021) undertaken a study to observe the effect of B and Mo on cauliflower and find out their suitable dose for higher yield. Results exhibited that the highest curd yield (40.00 ± 1.67 t ha^{-1}) was obtained from 3.0 kg ha^{-1} B + 1.5 kg ha^{-1} Mo (T_4) and the lowest yield (26.86 ± 1.39 t ha^{-1}) was obtained from the control. The highest gross return (US$ 5,600), gross margin (US$ 3,786), and benefit-cost ratio (3.06) were also found in T_4 treatment. So, it may be concluded that the application of

3.0 kg ha^{-1} B + 1.5 kg ha^{-1} Mo could be recommended for maximizing the curd yield of cauliflower in Bangladesh.

Jahan (2021) conducted a field experiment to study the response of boron and sulfur fertilization on morpho-physiological, yield and yield attributes of mustard. Experiment results concluded that, the highest plant height at 30, 45 and 60 DAS (52.37, 97.40 and 113.0 cm), maximum leaf number (16.07), highest number of branch per plant (10.07), maximum SPAD value of leaf (52.63), highest number of siliquae (137), maximum number of seeds $siliqua^{-1}$ (34.17), highest weight of 1000 of seeds (3.90 g), highest grain yield (1.64 t ha^{-1}), highest stover yield (3.97 t ha^{-1}), highest biological yield (5.62 t ha^{-1}) and highest harvest index (29.20%) were obtained from the combination of 1 Kg B ha^{-1} + 20 Kg S ha^{-1}.

Kamaleshwaran *et al.* (2021) conducted a field experiment to find out the effect of different levels and source of boron fertilizers on the growth and yield of groundnut in coastal saline soil. The fifteen treatments consisted of five levels of boron *viz*., 0, 0.5, 1.0, 1.5 and 2.0 kg B ha^{-1} as factor-L and three different sources of boron fertilizers like S_1– Borax; S_2– Solubor and S_3– Boro-Humate as factor-S. The results revealed that the combined application of B @ 1.5 kg ha^{-1} through Boro-Humate significantly increased the growth, yield characters and yield of groundnut.

Nandi *et al.* (2020) conducted an experiment in West Bengal in three levels of boron application *viz*., (0, 0.3 and 0.45% B foliar application) and results are reported that the plant height of groundnut was 35.6 cm at flowering and 41.5 cm at harvest stage.

Hirpara *et al.* (2019) conducted a pot experiment to evaluate soil application of boron and molybdenum and its effect on growth parameters, yield attributes, yield, nutrient content, uptake, and quality parameters of summer groundnut (*Arachis hypogaea* L.) and post harvest soil fertility. The experiment comprising of five levels of boron viz., 0, 2, 4, 8 and 10 kg B ha^{-1} and three levels of molybdenum *viz*., 0, 1, 2 kg Mo ha^{-1} and experiment was laid out in Factorial Completely Randomization Design and replicated thrice. The results revealed that the application of boron 8 kg B ha^{-1} and molybdenum 1 kg Mo ha^{-1} significantly increased the Growth parameters, yield attributes, yield, nutrient content, uptake, and quality parameters of summer groundnut (*Arachis hypogaea* L.) and post harvest soil fertility under medium black calcareous soils of south Saurashtra region of Gujarat.

Poonguzhali and Saravana (2019) conducted a field experiment in Madurai district with different levels of boron application in soil and foliar along with RDF and results are reported that the application of 15 kg ha^{-1} of B as soil application plus 0.5% foliar application of B at critical stages recorded the maximum plant height (61.7 cm), number of branches $plant^{-1}$ (14.5), number of nodules $plant^{-1}$ (107.6), maximum pod yield of 2013 kg ha^{-1} and the haulm yield of 3017 kg ha^{-1}.

Poonguzhali *et al.* (2019) conducted a field experiment to study the effect of boron on availability of boron in soils, yield and quality of groundnut in boron-deficient soil series of the Madurai district at the farmer's field located at Alangampatti village of Melur. Twelve treatments were included and the results revealed that the application of 15 kg ha^{-1} of B as soil application and 0.5 per cent of B as foliar application at critical stages of crop growth along with the recommended dose of fertilizers (RDF) resulted in maximum pod and haulm yield (2013 and 3017 kg ha^{-1}). Regarding the quality the application of soil (15 kg ha^{-1}) and foliar B (0.5%) along with RDF recorded the highest oil and protein content as compared to the other treatments.

Verma *et al*. (2018) conducted a field experiment to study the influence of boron on yield and economics of mustard and the results showed that the maximum net return of Rs. 22899 ha^{-1} and benefit cost ratio of 1.82 was obtained in the treatment receiving 2 kg ha^{-1} of B through soil application.

Kumar *et al.* (2016) conducted a field experiment to study the optimization of boron and magnesium on growth and yield parameters by groundnut in medium deep black soil at Agriculture College Farm, Raichur. The results revealed that combined application of (T_{10}): RDF + MgO 20 kg ha^{-1} + Borax 5 kg ha^{-1} recorded significant higher pod and haulm yield (1723 and 3101 kg ha^{-1}) fallowed by T_9 and T_8 as compare to control (983 and 1670 kg ha^{-1}). The soil application of RDF + 20 kg MgO ha^{-1} + 5 kg borax ha^{-1} found better in increasing pod and haulm yield evidenced by increased growth, yield attributes and uptake of nutrients.

Quamruzzaman *et al.* (2016) a field experiment was conducted to study the response of boron and light on morph-physiology and pod yield of two peanut varieties. Result revealed that days to first-last emergence and days to first-50% flowering took shorter times and vegetative growth, pods dry weight $plant^{-1}$, pod yield, and germination were markedly increased with the application of boron.

Quamruzzaman *et al.* (2016) conducted an investigation on boron deficient soil to evaluate the response of two groundnut cultivars (BARI Chinabadam-8 and Dhaka-1) to application of three boron's (B) rate (at 0, 1 and 2 kg ha^{-1}) and 2 levels of artificial lightening (Light and No-light) on protein, oil and vitamin E contents of groundnut seeds. Results exhibited that 2 kg B ha^{-1} increased all studied qualitative characters *viz.,* protein, oil and vitamin E contents of groundnut seeds. Application of B also increased the 100 seed weight.

Naiknaware *et al.* (2015) reported that four levels of boron viz., no boron (B0), 4 kg B ha^{-1} (B_1), 8 kg B ha^{-1} (B_2) and 12 kg B ha^{-1} (B_3) and three levels of elemental sulphur viz., no sulphur (S_0), 20 kg S ha^{-1} (S_1) and 40 kg S ha^{-1} (S_2). The results of the experiment revealed that the groundnut crop fertilized with 8 kg boron showed remarkably increased plant growth parameters *viz*., no. of pegs $plant^{-1}$ (43.88) and no. of nodules (102.00) at 50-55 DAS and yield attributes viz., numbers of pods per plant (10.83) and kernel yield (1214 kg ha^{-1}).

Ravinchandra *et al*. (2015) conducted a field experiment on groundnut for two kharif seasons during 2009 and 2010 at crop research farm of SHIATS, Allahabad to find out the effect of foliar spray of boron in combination of rhizobium inoculation on growth and yield of groundnut. Inoculation with rhizobium along with application of boron as foliar spray at flowering and pod formation stage had significant and positive effect on growth and yield of groundnut with increased plant height, number of branches, plant dry weight, number of pods $plant^{-1}$, 100 pods weight, seed index and pod yield. Excess spray of boron foliar nutrition led to decrease in the above mentioned parameters.

Ganie *et al*. (2014) conducted an experiment during Kharif 2011 to study the response of french bean to different levels of sulphur and boron. The treatment combination of $S_{45}B_{1.0}$ recorded significantly higher values for nodulation parameters like number of nodules, their fresh and dry weight, dry matter accumulation at flowering, pod picking and harvesting stages, pod yield, yield attributes like number of pods $plant^{-1}$, number of seeds pod^{-1} and test weight, seed yield, stover yield and protein content. The percent increase in these parameters over control was observed to be 210.90, 150.11, 164.88, 83.85, 61.55, 35.01, 42.33, 93.13, 30.80, 12.14, 27.13, 40.82 and 28.70, respectively. From the study it was concluded that for realizing higher yield and quality of french bean on inceptisols under temperate conditions of Kashmir valley, the nutrient management may centre around 45 and 1.0 kg ha^{-1} of sulphur and boron respectively, along with the recommended fertilizer dose of N, P, K and FYM. The post-harvest soil sample analysis showed that the treatment receiving1.5 kg B ha^{-1} increased the available soil nutrients *viz.* nitrogen, phosphorus, potassium, sulphur and boron.

Nadaf *et al.* (2013) studied the effect of zinc and boron on quality parameters and oil yield of groundnut. The results showed that protein content, oil content and oil yield of groundnut was significantly increased over the control due to application of boron @ 5 kg ha^{-1} and zinc sulphate at three level 5, 10 and 20 kg ha^{-1} either alone or in combination with borax.

Sathya *et al*. (2013) undertaken a investigation with tomato (PKM 1) as the test crop to study the effect of application of boron on boron fractions *viz.*, readily soluble, specifically adsorbed, oxide bound, organically bound, residual and total boron in boron deficient soil of Madukkur soil series. The results indicated that the application of 20 kg borax ha^{-1} recorded the highest mean value of boron fractions *viz.*, readily soluble (0.33 ppm), specifically adsorbed (0.27 ppm), oxide bound (0.85 ppm), organically bound (0.12 ppm), residual (34.03 ppm) and total boron (35.59 ppm). Among all five fractions, residual boron contributed nearly 96.36 to 97.83% to total boron at harvest stage of crop. The results also revealed that the soil application of borax @ 20 kg ha^{-1} recorded the highest level of available boron, nitrogen, and phosphorus and potassium status in post-harvest soil.

Ansari *et al*. (2013) conducted a field experiment to study the efficacy of boron sources on productivity, profitability and energy use efficiency of groundnut (*Arachis hypogaea* L.) under North East Hill regions. Application of boron reduced days to 50% flowering by 4-5 days over control. The 50% days of flowering and number of pods/plant were found linearly (R^2=0.71 and 0.67, respectively) related with dry pod yield of groundnut. However, significantly higher dry pod yield and haulm yield were recorded with solubor (Soil application) (3.5 and 4.72 tonnes ha^{-1}), which was 29 and 24% higher than control (2.71 and 3.82 tonnes ha^{-1}), respectively. 3% more shelling percent was found in solubor (Soil application) than control. The groundnut productivity (₹ 570.4 ha day^{-1}), net returns (₹79.8 × 103 ha^{-1}) and B: C ratio (5.45) as well as energy use efficiency (11.3) and energy productivity (0.36 kg Mj^{-1}) were recorded maximum with solubor (soil application) followed by borosol (soil application) over no boron application.

Kabir *et al.* (2013) conducted an experiment and show the effect of phosphorus, calcium and boron on the growth and yield of groundnut and revealed that application of 2.5 kg boron ha^{-1} significantly increased plant height and leaf area index over application of 2.0 kg boron ha^{-1} on silty loam soil of Bangladesh.

Elayaraja and Singaravel (2012) conducted a field experiment to find out the effect of micronutrients *viz*., Zn and B on the yield and nutrients uptake by groundnut in coastal sandy soil. The results clearly indicated that, T_6- 150% NPK + $ZnSO_4$ @ 30 kg ha^{-1} + Borax @ 15 kg ha^{-1} along with composted coirpith application significantly increased the yield and nutrients uptake by groundnut. This treatment recorded the highest pod yield of 2466 kg ha^{-1} and haulm yield of 3354 kg ha^{-1} which represented 31.31 and 25.95 per cent increased in pod and haulm yield, respectively over 100 per cent NPK application. Experiment results also concluded that the highest amount of available soil nutrients such as N, P, K, Fe, Mn, Zn and Cu were observed in the treatment receiving 25 kg ha^{-1} Borax at three stages of crop growth such as flowering, peg formation and at harvest stage.

Mohapatra and Dixit (2010) investigated the effect of integrated use of FYM, recommended dose of fertilizer, Rhizobium, gypsum and boron on performance of groundnut and soil fertility. The results revealed that application of FYM+75 per cent RDF + *Rhizobium* + gypsum + boron recorded significantly higher uptake of N, P, K, and B.

Sonawane *et al*. (2010) found that the application of micronutrients resulted in increase in dry matter and pod yield of groundnut. They concluded that combined application of 20 kg Zn + 5 kg borax + RDF had registered an increase in pod yield of 49.94 per cent as compared to RDF alone.

3.3. Combined response of calcium and boron on yield and seed quality

Cardoso *et al.* (2022) carried out a research was to evaluate the production and quality of sweet pepper seeds with calcium and boron application directed to flowers and fruits. Experimental results concluded that both the application of calcium and boron did not affect the physiological quality of the seeds. Boron application reduced seed production and the 1000 seeds weight, while calcium application increased the number of pollen grains, seed production and seed albumin content, and, therefore, the application of calcium in the production of sweet pepper seeds is recommended.

Galeriani *et al.* (2022) carried out a study to investigate the effects of Ca + B fertilization during flowering on the nutritional, metabolic and yield performance of soybean (*Glycine max* L.) The treatments consisted of the presence and the absence of Ca + B fertilization in two growing seasons. Crop nutritional status, gas exchange parameters, photosynthetic enzyme activity (Rubisco), total soluble sugar content, total leaf protein concentration, agronomic parameters, and grain yield were evaluated. Foliar Ca + B fertilization increased water use efficiency and carboxylation efficiency, and the improvement in photosynthesis led to higher leaf sugar and protein concentrations. The improvement in metabolic activity promoted a greater number of pods and grains plant^{-1}, culminating in higher yields. These results indicated that foliar fertilization with Ca + B can efficiently improve carbon metabolism, resulting in better yields in soybean.

Kumar *et al*. (2022) conducted a experiment to study the impact of boron and calcium on growth and yield o groundnut *cv.* BG-4 (*Arachis hypogaea* L.) under red and lateritic soil (Alfisols) of Jharkhand, India. The significantly superior improvement was observed in plant height and number of pegs and pods per plant in where plot was treated with lime @ 1/5 LR followed by @ 1/10 LR and @1/15 LR among the mean values of both years i.e., 2017 and 2018. In case of grain and straw yield, significantly increased with increasing boron application, in where significantly higher was observed in B_3 (@ 3.0 kg B ha^{-1}) followed by B_2 (@ 2.0 kg B ha^{-1}) and B_1 (@ 1.0 kg B ha^{-1}) among the mean values of both years. The optimum improved in growth and yield of groundnut was recorded from where boron application at the rate of 3.0 kg ha^{-1} and lime application @ 1/5 LR.

Mansingh *et al.* (2022) carried out a field to investigate the interaction impact of calcium and boron on increasing groundnut yield in the Vylogam soil series in Madurai district during the rabi season 2019. The treatment receiving Ca @ 150 kg ha^{-1} and B 1.5 kg ha^{-1} was proved to be the most effective in improving growth and yield characteristics. The interaction of calcium and boron exhibited a strong synergistic relationship at Ca_{150} $B_{1.5}$ kg ha^{-1} on growth and yield of groundnut (VRI 2) with pod yield (2317 kg ha^{-1}) and haulm yield (3463 kg ha^{-1}).

Ramya *et al*. (2022) conducted a field experimental to investigate the effect of gypsum and boron on yield and economics of groundnut. 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^{-1}), haulm yield (3345.13 kg ha^{-1}) and harvest index (44.43%) compared to all other treatment combinations. They also reported that 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. The use of boron at a rate of 10 kg ha^{-1} resulted in improved plant growth and yield indices, as well as improved groundnut crop economics.

Ramya and Singh (2022) conducted a field experiment to evaluate the effect of gypsum and boron on growth and yield of groundnut. From the results, it was observed that the growth parameters *viz.*, plant height (64.67 cm), dry weight (42.29 g $plant^{-1}$), number of nodules $plant^{-1}$ (38.71), crop growth rate (12.18g $m^{-2}day^{-1}$) were recorded highest in the treatment 8 with the application of 400 kg ha^{-1} gypsum + boron 10 kg ha^{-1}. Whereas, relative growth rate (0.0150 g/g/day) recorded maximum with application of 400 kg ha^{-1} gypsum and 5 kg ha^{-1} boron. The yield parameters and yield *viz.*, No. of pods $plant^{-1}$ (31.36), shelling percentage (71.65%), Seed yield (2674.17 kg ha^{-1}), Haulm yield (3345.13 kg ha^{-1}), harvest index (44.43%) were also recorded highest with the treatment of gypsum at 400 kg ha^{-1} and boron 10 kg ha^{-1}.

Chirwa *et al.* (2017) conducted a field study to improve kernel yields by assessing the effect of B, Ca, N, P and K fertilizer application on groundnuts at Golden Valley Agricultural Trust (GART) in Chisamba District of Zambia for two consecutive growing seasons of 2014-15 and 2015-16. They observed a positive interaction effect between Ca and B on improving the plant height. Compared to the control (0 kg $ha^{-1)}$, groundnuts responded to the application of $N_{20}P_{30}Ca_{100}K_{40}B_1$ kg ha^{-1} to result in an increase of Ca uptake by 21%, N uptake by 55.5% and P uptake by 51%. . The response of groundnuts to $N_{20}P_{30}Ca_{100}$ kg ha^{-1} resulted in an increase in kernels by 65.5% and haulm yield by 83.4%.

Rathod *et al*. (2017) conducted a field experiment at Botany farm, College of Agriculture, Dapoli Konkan (Maharashtra) to study the effect of lime, zinc and boron on soybean yield and uptake of nutrients. The results of the experiment showed significantly increased the grain (25.52 q ha^{-1}) and straw (37.29 q ha^{-1}) yield of soybean due to application of 1 L.R+ Zn +B through soil and foliar spray along with RDF. The uptake of N, P, K, Ca, Mg and S by soybean was also significantly increased by this treatment.

Kabir *et al.* (2013) carried out an experiment to find out the effect of phosphorus, calcium and boron on the growth and yield of groundnut and 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.

Jena *et al*. (2009) carried out a field experiment in the lateritic soils of Bhubaneswar to study the effect of lime and boron on yield and nutrient content of cabbage. The results revealed that liming and boron (B) application has significant effect on cabbage yield, which varied between 39.9 to 62.0 t ha^{-1}. Highest significant yield of 62.11 t ha^{-1} was obtained with 0.2 lime requirement (LR) + B @ 2 kg ha^{-1}). The yield of cabbage increased with levels of lime up to 0.2 LR but thereafter it declined at 0.3 LR. With application of lime the cabbage yield was increased by 21 to 31% over control (L_0B_0) at 0.1 LR to 0.2 LR. With application of B there was increase in yield by 16 and 22 % over control at boron 1 kg (B_1) and boron 2 (B_2) kg levels, respectively although the yield at B_1 and B_2 were non- significant.

Wen-Xin *et al*. (2001) carried out a study to investigate the effects of calcium and boron on the growth, yield and quality of peanut. The results showed that the application of Ca fertilizer increased yield and quality of peanut; the application of B fertilizer improved quality of peanut but give negative effect in yield; combined application of Ca and B also increased yield of peanut and Ca fertilizer was the main effect. The application Ca and B fertilizer not only increased Ca and B contents in peanut plant during maturity, but also significantly increased residual Ca and B in soil.

CHAPTER III

MATERIALS AND METHODS

In this chapter, the experimental site, climate, soil preparation, experimental design layout, intercultural operations, data collection, and data analysis are briefly discussed.

3.1. Description of the experimental site

3.1.1. Location

The experiment was conducted at the Research Field of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, during the period from March 24 to July 29, 2021 to study the effect of calcium and boron on yield and seed quality of groundnut. The experimental filed is located at 230 41' N latitude and 900 22' E longitude at a height of 8.6 m above the sea level belonging to the Agro-ecological Zone "AEZ-28" of Madhupur Tract (BBS, 2021).

3.1.2. Climate

The climate of the experimental site was sub-tropical, characterized by the winter season from November to February and the pre-monsoon period or hot season from March to April and the monsoon period from May to October (Edris *et al*., 1979). The experiment was conducted during *Kharif* season. Temperature was high; rainfall was scanty during the experiment period. Meteorological data related to the temperature, relative humidity and rainfall during the experimental period were collected from mini weather station, Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka and has been presented in Appendix-IV.

3.1.3. Soil

The soil of the research field was slightly acidic in reaction with low organic matter content. Soils was general type, hallow red brown terrace soils under Tejgaon series, clay loam in texture. The selected research plot was above flood level and sufficient sunshine was available and was also available irrigation and drainage system during the experimental period. The experimental plot was high land having pH 6.2, organic carbon 0.45 %. Soil sample from 0-15 cm depth were collected from experimental field and the soil analysis were done from Soil Resources Development Institute (SRDI), Dhaka. The physical and chemical properties of the soil are presented in Appendix II.

3.2. Materials

3.2.1. Test crop

BARI Chinabadam-10 was used as test crop in this experiment. Seeds were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur. According to Azad *et al*. (2020) BARI Chinabadam-10 is a high yielding, drought tolerant and disease resistant variety released by BARI in 2016. The pedigree line ICGV-96346 of the variety was collected from ICRISAT (International Crop Research Institute for the Semi Arid Tropic). This is a Spanish class variety. It takes about 140-150 days to mature in *rabi* season and 120-130 days during *kharif* season. It attains a plant height of 40-45 cm at maturity, contains 20-22 nuts per plant, average yield 2-2.2 tha^{-1}.

3.2.2. Fertilizers

Urea, TSP, MoP, Gypsum and Boric acid were used as sources of N, P, K, Ca and B, respectively.

3.3. Treatments

The experiment consisted of 2 factors:

Factor A: Calcium level (Source: Gypsum, contain approximately 23.3% Ca)

a) Ca_1 = 0 kg Ca ha^{-1} (0 kg gypsum ha^{-1}) (Control)
b) Ca_2 = 50 kg Ca ha^{-1} (250 kg gypsum ha^{-1})
c) Ca_3 = 60 kg Ca ha^{-1} (300 kg gypsum ha^{-1})
d) Ca_4 = 70 kg Ca ha^{-1} (350 kg gypsum ha^{-1})

Factor B: Boron level (Source: Boric acid, contain approximately 16.5% B)

a) B_1 = 0 kg B ha^{-1} (0 kg boric acid ha^{-1}) (Control)
b) B_2 = 1.275 kg B ha^{-1} (7.5 kg boric acid ha^{-1})
c) B_3 = 1.7 kg B ha^{-1} (10 kg boric acid ha^{-1})
d) B_4 = 2.125 B ha^{-1} (12.5 kg boric acid ha^{-1})

3.4. Experimental preparation

3.4.1. Land preparation

The plot selected for the experiment was opened in the first week of March, 2021 with a power tiller and was exposed to the sun for a week, after one week the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth and final land was prepared on 20 March, 2021. All weeds, stubbles and crop residues were removed from the experimental field.

3.4.2. Experimental design

The experiment was laid in a split-plot design with three replications. Each experimental unit was divided into three blocks each of which representing a replication. The total numbers of unit plots were 48. The size of unit plot was 3.8 m × 1.8 m. Spacing was maintained 30 cm × 15 cm. Distances between plot to plot and replication to replication were 1m and 1.5 m, respectively. Ca was applied in the main-plots and B was applied in the sub-plots. Layout of the experimental plots presented in Appendix III.

3.4.3. Collection and preparation of initial soil sample

Before preparing the land, the initial soil samples were taken from a soil depth of 0 to 15 cm. To create a composite sample, the samples were properly mixed after being dug out using an auger from various locations throughout the experimental plot. After obtaining soil samples, plant roots, leaves, and other components were cleaned out and eliminated. The samples were then air dried, put through a 10-mesh filter, and kept in a clean plastic container for later physical and chemical analysis at the Soil Resources Development Institute (SRDI), Farmgate, Dhaka-1215.

3.4.4. Fertilizer application

The following doses of manure and fertilizer were used: urea: 25 kg ha^{-1}, 160 kg ha^{-1}, 75 kg ha^{-1} applied according to BARC, (2018) and gypsum and boric acid were applied as per treatment. Half of urea and other fertilizers were applied as per treatment 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 as per treatment.

3.4.5. Collection of seeds

BARI Chinabadam-10 seeds were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.4.6. Seed germination test

Before planting the seeds in the main plot, a laboratory germination test was conducted. Petridishes were employed in the laboratory tests. Each petridish and container received 25 seeds that were distributed separately. Days to emergence were computed using the following calculation on a percentage basis:

$$\text{Germination percentage (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number seeds set for germination}} \text{ X } 100$$

3.4.7. Seed sowing

Seeds were sown at the rate of 100 kg ha^{-1} (unshelled groundnut) on 31 March, 2021. Before sowing seeds were unshelled and were treated with Provax-200 Ec @ 2.5 g powder kg^{-1} seed. As a good tilth condition, furrows were made with hand rakes for sowing. After providing slight water in each line, seeds were 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 2-3 cm depth.

3.5. Intercultural operations

The following intercultural operations were done for the better growth and development of the plants during the period of the experiment:

3.5.1. Irrigation and drainage

Pre-sowing irrigation was given to ensure the maximum germination percentage. Generally for upland soil 3 irrigations are required *viz.*, after 20 days of planting, during flowering stage, and at the pegging and pod formation stage. 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.

3.5.2. Gap filling, weeding and earthing-up

Gap filling were done at 20 and 23 DAS, respectively to maintain the uniformity of plant population. Weeding was accomplished as and when necessary to keep the crop field free from weeds and to break the soil crust. Two level of earthing up were done, the first just before flowering and the second one during pegging stage.

3.5.3. Plant protection measures

To prevent the plant from fungal infection, Rovral @ 2 g L^{-1} was applied at 15 days of interval. To control seeds from ant, Sevin 85 Ec was applied. To prevent plants from other insects, Admire 200 SL @ 1 ml $liter^{-1}$ water and Ripcord 10 EC @ 1 ml $litre^{-1}$ water were mixed and then sprayed on the leaves two times by knapsack sprayer.

3.5.4. Harvesting

After observing some maturity indices such as yellowing leaves, spots on the leaves, hard and tough pods and dark tannin discoloration inside the shell, crops were harvested at 29 July, 2021. The plants were taken to the threshing floor and washed with running tap water. After washing leaves, stems, roots, pegs and pods were separated and data were recorded.

3.6. Data collection

Experimental data were recorded from germination and continued until harvest. The following data were recorded during the experimentation.

3.6.1. Crop growth parameters

a) Plant length (cm)
b) Number of leaves $plant^{-1}$

3.6.2. Yield and yield contributing characters

a) Number of branches $plant^{-1}$
b) Number of pods $plant^{-1}$
c) Pod length (cm)
d) 100-seed weight (g)
e) Seed yield (t ha^{-1})

f) Stover yield (t ha^{-1})

g) Biological yield (t ha^{-1})

h) Harvest index (%)

3.6.3. Seed quality contributing characters

a) Germination percentage (%)

b) Protein content (%)

c) Oil content (%)

d) Vitamin E content (mg/100 g seed)

3.7. Detailed Procedures of data collection

3.7.1. Crop growth parameters

3.7.1.1. Plant length (cm)

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

3.6.1.2. Number of leaves $plant^{-1}$

Five plants were selected randomly from the inner row of each plot for sampling. Leaves $plant^{-1}$ was counted from each sample plant and then averaged (at 25, 50, 75, 100 DAS and during harvesting).

3.7.2. Yield and yield contributing characters

3.7.2.1. 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 averaged at 25, 50, 75, 100 DAS and during harvesting. Then the average data were recorded.

3.7.2.2. Number of pods $plant^{-1}$

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

3.7.2.3. Pod length (cm)

The pod length (cm) was counted from five randomly selected plants. It was done by measuring length of all collected pods from selected plants then average them and recorded in centimeter.

3.7.2.4. 100-seed weight (g)

Weight of 100 sun-dried seeds was taken using an electric balance expressing in gram.

3.7.2.5. Seed yield (t ha^{-1})

Seed yield was calculated from unshelled, cleaned and well dried grains collected from the central 2 m^2 area of all 4 inner rows of the each plot (leaving two boarder rows) and expressed as t ha^{-1} on 8 % moisture basis.

3.7.2.6. Stover yield (t ha^{-1})

Stover yield was determined from the central field. 2 m^2 area of 4 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}.

3.7.2.7. Biological yield (t ha^{-1})

It was the total yield including both the economic and stover yield.

Biological yield (t ha^{-1}) = Grain yield (t ha^{-1}) + Stover yield (t ha^{-1})

3.7.2.8. Harvest index (%)

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

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

3.7.3. Seed quality contributing characters

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

3.7.3.1. 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).

3.7.3.2. Oil content (%)

In order to determine the oil content in groundnut seed, the soxhlet extraction method (AOAC, 1990) was used by Inuwa *et al*., (2011) was followed.

3.7.3.3. Vitamin E content (mg/100 g seed)

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

3.7.3.4. 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 petridish to evaluate the percentage of seed germination. The number of germinated seeds were counted and finally germination percentage was recorded.

$$\text{Germination percentage (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number seeds set for germination}} \times 100$$

3.8. 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 differences were adjusted by Least Significance difference (LSD) test at 5% level of significance (Gomez and Gomez, 1984).

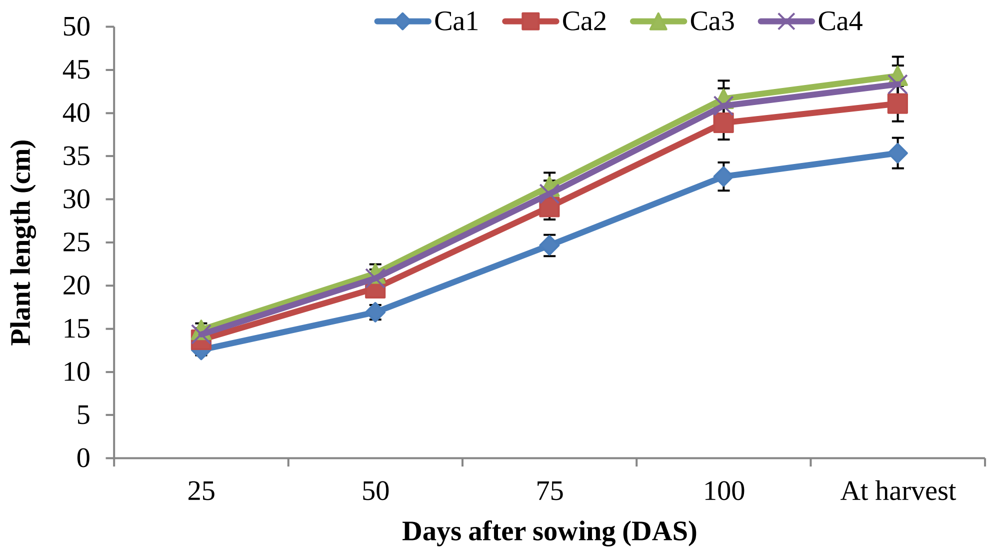
CHAPTER IV

RESULTS AND DISCUSSION

This chapter represents the result and discussions of the present study. The experiment was conducted to evaluate the response of calcium and boron on the yield and seed quality of groundnut *cv*. BARI Chinabadam-10. Data on yield and seed quality of groundnut was recorded. Summary of mean square values at different parameters are also given in the appendices from V to X. The results have been presented and discussed with the help of graphs and tables and possible interpretations has been given under the following headings:

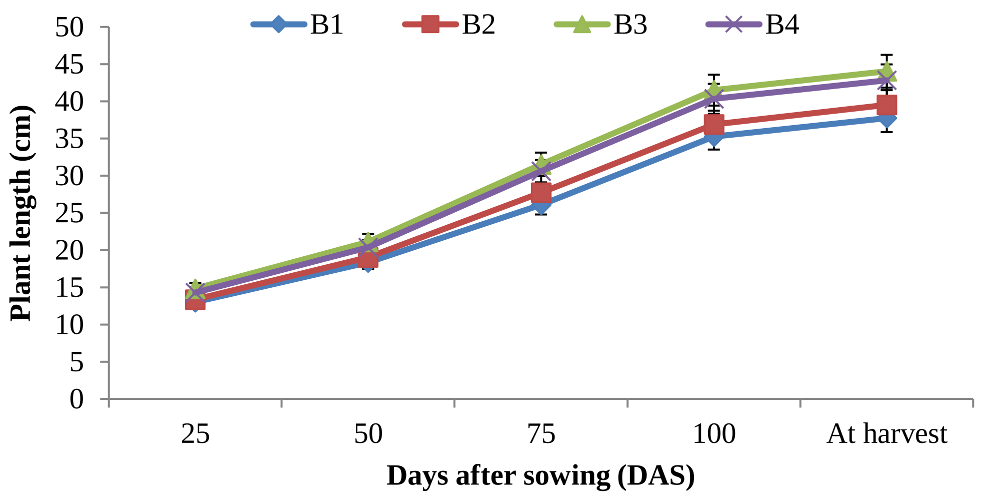
4.1. Effect of calcium and boron on plant length (cm) of groundnut

Calcium showed statistically significant variations on plant length of groundnut with the application of different doses of gypsum as a source of calcium (Figure 1 and Appendix V). Data revealed that Ca_3 (60 kg Ca ha^{-1}) produced the highest plant length 14.88, 21.4, 31.51, 41.67 and 44.31 cm at 25, 50, 75, 100 DAS and during harvest time, respectively. The lowest plant length recorded from Ca_1 (Control) treatment at all growth stages of groundnut. The increase in plant length might be due to the increased supply of calcium through gypsum and associated nutrients might have helped in rapid cell multiplication and higher chlorophyll content, thereby accelerating photosynthesis rate and activity and eventually more supply of assimilates to plants that in turn increased the growth in terms of a greater canopy, plant height at the successive growth stages (Ramya and Singh, 2022). Mansingh and Suresh (2019) reported that calcium increased the nutrient supply to the plants and played a vital role in photosynthesis, carbohydrates metabolism, protein synthesis, synthesis of growth stimulating substances, cell division, and cell elongation would have resulted in increased height. Kamara *et al.* (2017) and Das *et al.* (2015) supported the findings of this experiment and reported that different levels of gypsum had significant effect on growth and yield of groundnut.



Here, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 1. Effect of calcium on plant length at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.22, 0.27, 0.59, 1.24 and 0.78 at 25, 50, 75, 100 DAS and at harvest, respectively).



Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 2. Effect of boron on plant length at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.35, 0.46, 0.62, 0.88 and 0.85 at 25, 50, 75, 100 DAS and at harvest, respectively).

Plant length showed significant variations with the application of different doses of boron (Figure 2. and Appendix V). Experimental results revealed that B_3 (1.7 kg B ha^{-1} as B source) treatment produced the highest plant length 14.83, 21.11, 31.53, 41.5 and 44.04 cm at 25, 50, 75, 100 DAS and during harvest time, respectively. This might be due to the essentiality of boron for improving carbohydrate metabolism, sugar transport, cell wall structure, protein metabolism, root growth, and promoting other plant physiological activities (Mansingh *et al*., 2022). Kumar *et al.* (2016) stated that boron is required for N fixation, which could have ensured better N supply to the crop and increased the plant length. Similar positive results on effect of boron on groundnut plant length reported by Haneena *et al*., (2021), Hossain *et al*., (2021) and Nandi *et al*., (2020).

Interaction effect of calcium and boron was significant on plant length at different levels of growth stages of groundnut (Table 1. and Appendix V). Experiment results concluded that maximum plant length 16.44, 23.19, 34.42, 45.00 and 47.62 cm at 25, 50, 75, 100 DAS and at harvest time, respectively were observed with Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment and lowest plant length with Ca_1B_1 treatment, which clearly indicates that both the nutrients are synergistic and they mutually help in their absorption and utilization by the groundnut. Chirwa *et al.* (2017) observed a positive interaction effect between Ca and B on improving the plant length. Mansingh *et al*. (2022) reported that at the vegetative, flowering and at harvest stages the combined application of Ca_{150} $B_{1.5}$ kg ha^{-1} registered the highest plant length of 39.2, 55.6, and 57.3 cm respectively. Cardoso *et al.* (2022), Galeriani *et al*. (2022), Kumar *et al*. (2022) and Kabir *et al*. (2013) also supported the findings of this experiment.

4.2. Effect of calcium and boron on number of leaves plant^{-1} of groundnut

Significant variations were observed on number of leaves plant^{-1} due to the application of calcium throughout the growing season (Figure 3 and Appendix VI). Number of leaves plant^{-1} was increased up to 100 DAS and then decreased up to harvest in all the calcium applied treatments. That may be due to plant focus on reproductive growth instead of vegetative growth. The number of leaves plant^{-1} was increased with the increasing level of Ca up to 60 kg Ca ha^{-1} and thereafter decreased. The highest number of leaves plant^{-1} 14.83, 30.46, 37.44. 42.36 was recorded in Ca_3

(60 kg Ca ha^{-1}) treatment at 25, 50, 75 and 100 DAS, respectively. The lowest number of leaves plant^{-1} was recorded from Ca_1 (control) treatment.

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

Treatment Combinations	Plant length (cm) at				
	25DAS	50 DAS	75 DAS	100DAS	Harvest
Ca_1B_1	12.22 h	16.25 j	23.24 k	30.72 j	33.45 k
Ca_1B_2	12.56 gh	16.64 j	24.70 j	32.01 ij	34.85 jk
Ca_1B_3	12.77 gh	17.70 hi	25.68 h-j	34.06 h	37.12 hi
Ca_1B_4	12.65 gh	17.06 ij	24.98 ij	33.78 hi	36.03 ij
Ca_2B_1	12.92 g	18.15 gh	26.02 g-i	35.22 gh	37.85 gh
Ca_2B_2	13.20 fg	18.75 fg	26.52 gh	36.34 fg	38.42 gh
Ca_2B_3	14.54 cd	21.19 c	32.52 bc	42.82 bc	44.64 cd
Ca_2B_4	14.25 de	20.76 cd	31.40 cd	41.12 cd	43.48 de
Ca_3B_1	13.72 ef	19.64 e	28.15 f	38.11 ef	40.45 f
Ca_3B_2	14.07 de	20.66 cd	30.26 de	40.04 d	42.63 e
Ca_3B_3	16.44 a	23.19 a	34.42 a	45.00 a	47.62 a
Ca_3B_4	15.30 b	22.10 b	33.22 ab	43.54 ab	46.55 ab
Ca_4B_1	13.20 fg	19.35 ef	26.95 fg	37.09 fg	39.21 fg
Ca_4B_2	13.61 ef	20.13 de	29.39 e	39.21 de	42.17 e
Ca_4B_3	15.58 b	22.37 ab	33.48 ab	44.09 ab	46.76 ab
Ca_4B_4	14.95 bc	21.48 bc	32.77 b	42.89 bc	45.22 bc
$LSD_{(0.05)}$	**0.70**	**0.91**	**1.23**	**1.76**	**1.71**
CV (%)	**3.03**	**2.77**	**2.52**	**2.72**	**2.47**

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, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}; Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}.

Calcium increased nutrient supply to plants and was essential in photosynthesis, carbohydrates metabolism, protein synthesis, synthesis of growth stimulating substances, cell division, and cell elongation, which would have resulted in an increase in the number of leaves plant^{-1} (Mansingh and Suresh, 2019). Ullah *et al.*

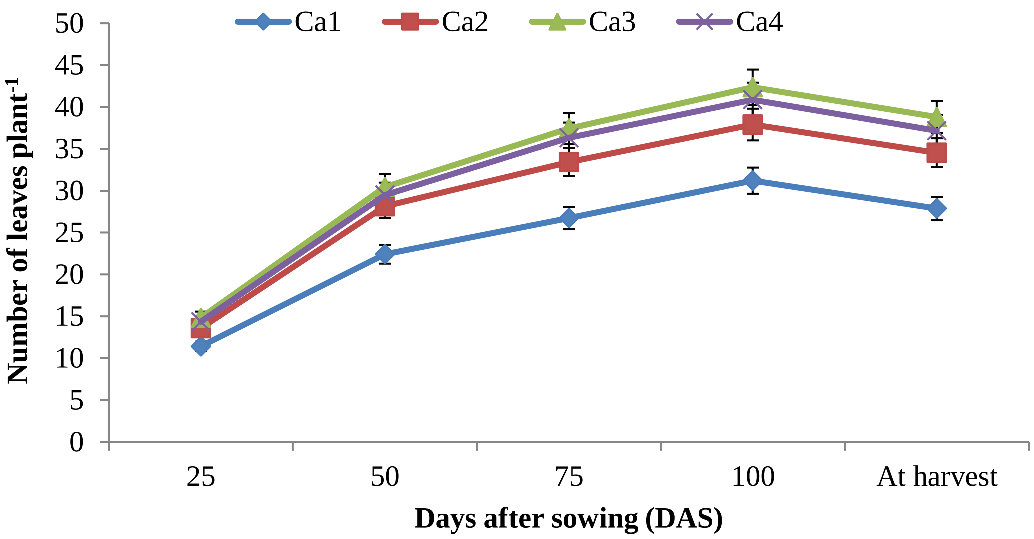
(2019) conducted an experiment to investigate the effect of gypsum application on groundnut growth and nodules under rainfed condition and reported that gypsum application increased number of leaves plant^{-1}. Kamara *et al.* (2017) and Das *et al.* (2015) supported the findings of this experiment.

Number of leaves plant^{-1} showed significant variations in efect of boron throughout the growing season (Figure 4 and Appendix VI). Among all boron applications, the number of leaves plant^{-1} increased up to 100 DAS and thereafter decreased up to harvest. This could be due to the plant's preference for reproductive growth over vegetative growth. The B_3 (1.7 kg B ha^{-1}) treatment produced the maximum leaves plant^{-1} (14.77, 29.94, 37.63, and 41.98) at 25, 50, 75, and 100 DAS, respectively and the lowest number of leaves plant^{-1} recorded from B_1 (control) treatment at all growth phases. Betterment in number of leaves plant^{-1} of groundnut might be due to the combined application of NPK along with boron increased the cell multiplication, photosynthesis rate and activity and eventually more supply of assimilates to plants that in turn increased the growth in terms of a greater canopy, plant height at the successive growth stages (Ramya and Singh, 2022). The findings of this experiment conform to Sathya *et al.,* (2013), Verma *et al*., (2018) and Khuong *et al.*, (2022).

Combined application of calcium and boron showed significant variations on number of leaves plant^{-1} at different levels of growth stages of groundnut (Table 2. and Appendix VI). Experimental results concluded that maximum number of leaves plant^{-1} 16.33, 33.00, 42.67, 46.75, 43.67, at 25, 50, 75, 100 DAS and at harvest time, respectively observed with Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment and lowest number of leaves plant^{-1} with Ca_1B_1 treatment, which clearly indicates that both the nutrients are synergistic and they mutually help in their absorption and utilization by the groundnut and increase number of leaves plant^{-1}. Cardoso *et al.* (2022), Galeriani *et al*. (2022), Kumar *et al*. (2022) and Kabir *et al*. (2013) also supported the findings of this experiment.

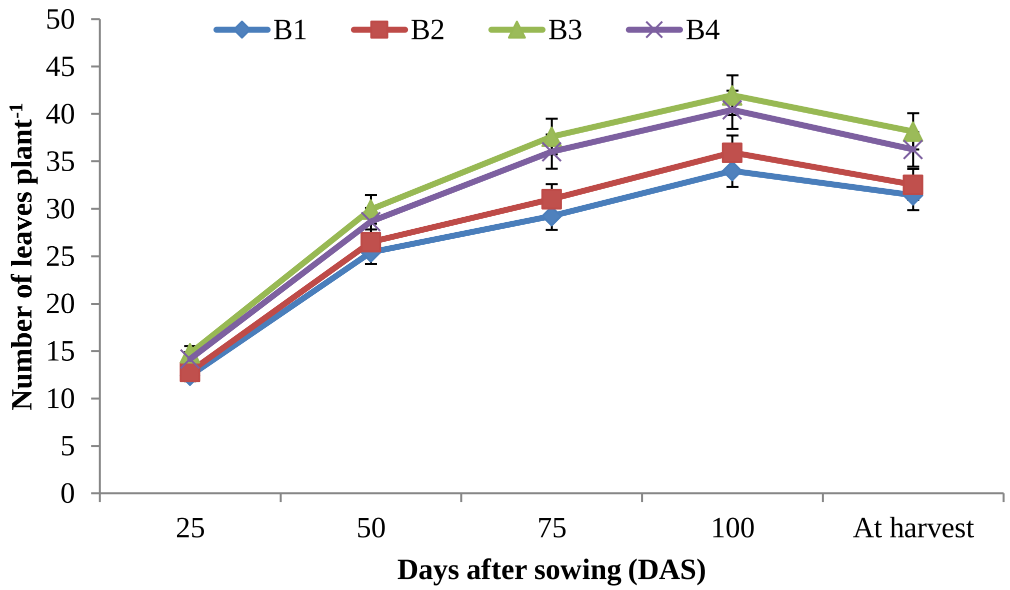
4.3. Effect of calcium and boron on number of branches plant^{-1} of groundnut

Number of branches plant^{-1} of groundnut showed statistically significant variations due to different levels of calcium application at 25 DAS, 50 DAS, 75 DAS and 100 DAS and at harvest (Figure 5 and appendix VII). Experimental data revealed that 60 kg Ca ha^{-1} produced the highest number of branches plant^{-1} and the lowest number of branches plant^{-1} produced from control treatment. Data also revealed that branches palnt^{-1} follow downward curve after 100 DAS, this may be due to plant focus on reproductive growth compared to vegetative growth.



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 3. Effect of calcium on number of leaves plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.24, 0.59, 1.11, 1.19 and 0.95 at 25, 50, 75, 100 DAS and at harvest, respectively).



Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 4. Effect of boron on number of leaves plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.29, 0.66, 0.81, 0.82 and 0.87 at 25, 50, 75, 100 DAS and at harvest, respectively).

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

Treatment Combinations	Number of leaves plant^{-1} at				
	25DAS	**50 DAS**	**75 DAS**	**100DAS**	**Harvest**
Ca_1B_1	10.67 k	20.75 j	25.33 l	30.00 j	26.67 k
Ca_1B_2	11.00 k	21.50 ij	26.00 kl	30.67 ij	27.50 jk
Ca_1B_3	12.33 i	24.75 h	28.33 ij	32.50 gh	29.00 ij
Ca_1B_4	11.67 j	22.67 i	27.33 jk	31.67 hi	28.33 jk
Ca_2B_1	12.50 hi	26.00 gh	29.33 hi	33.00 gh	32.33 h
Ca_2B_2	12.67 hi	26.50 fg	29.75 hi	33.67 g	30.50 i
Ca_2B_3	14.67 d	30.33 cd	38.00 de	43.33 c	38.33 de
Ca_2B_4	14.50 de	29.75 d	36.67 e	41.67 d	37.00 ef
Ca_3B_1	13.50 fg	27.67 ef	31.67 g	37.33 ef	34.33 g
Ca_3B_2	14.00 ef	29.67 d	34.75 f	40.67 d	36.50 f
Ca_3B_3	16.33 a	33.00 a	42.67 a	46.75 a	43.67 a
Ca_3B_4	15.50 bc	31.50 bc	40.67 bc	44.67 bc	40.75 bc
Ca_4B_1	13.00 gh	27.33 ef	30.67 gh	35.67 f	32.33 h
Ca_4B_2	13.67 f	28.33 e	33.67 f	38.75 e	35.75 fg
Ca_4B_3	15.75 b	31.67 b	41.50 ab	45.33 ab	41.67 b
Ca_4B_4	15.00 cd	30.67 b-d	39.50 cd	43.75 bc	39.00 cd
$LSD_{(0.05)}$	**0.58**	**1.32**	**1.63**	**1.64**	**1.75**
CV (%)	**2.57**	**2.90**	**2.89**	**2.57**	**3.01**

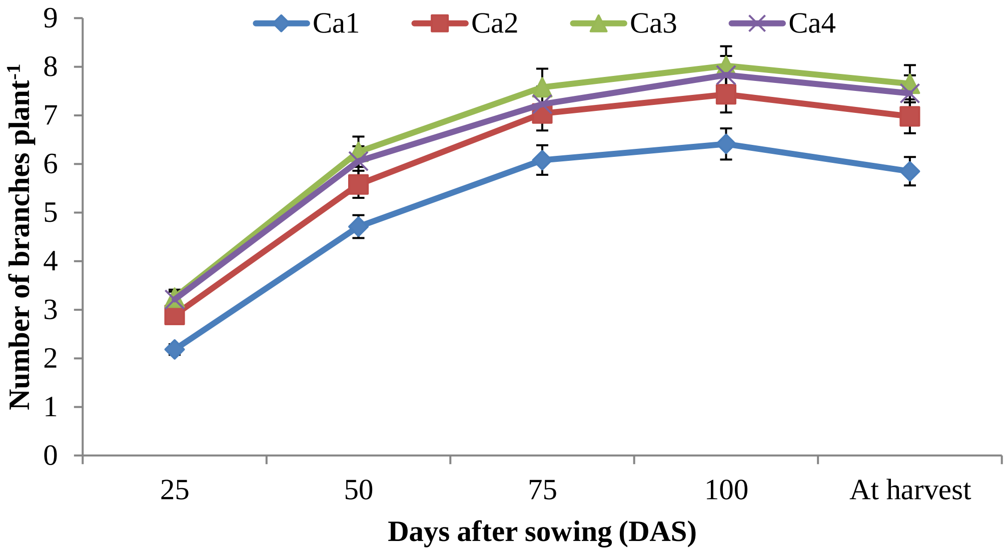
In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Here, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}; Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}.

Mansingh and Suresh, (2019) reported that calcium increased the amount of nutrients supply, which was crucial for photosynthesis, metabolism of carbohydrates, cell division, cell elongation, protein and growth stimulator synthesis, all of which would have increased the number of branches plant^{-1}. Ransing *et al*. (2021), Vaishnav *et al*. (2022) and Inban *et al*. (2022) also supported the findings of this experiment.

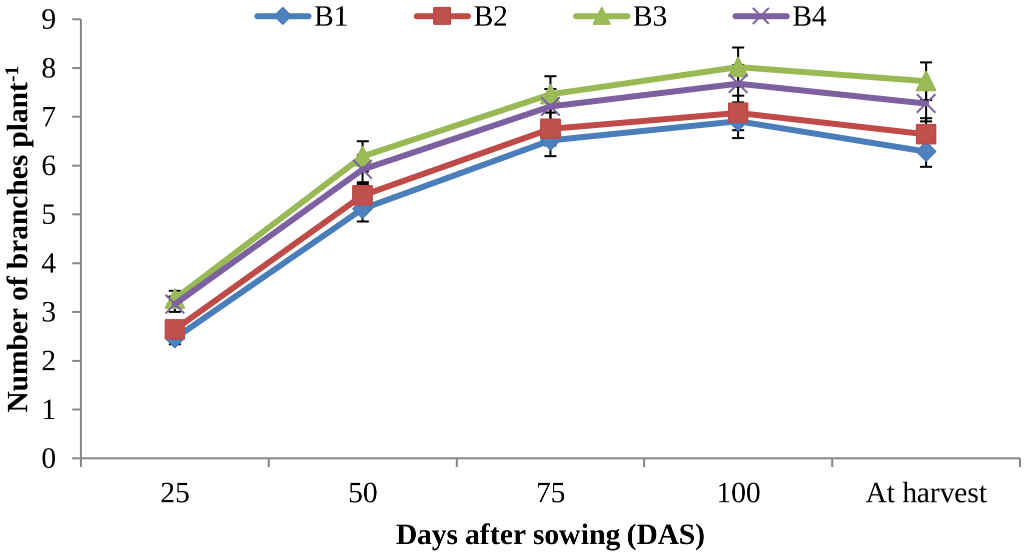
Significant variations were observed on number of branches plant^{-1} due to different application of boron throughout the growing season (Figure 6 and Appendix VII). Results revealed that the highest number of branches plant^{-1} 3.27, 6.19, 7.46, 8.02 and 7.73 recorded with treatment B_3 (1.7 kg B ha^{-1}) at 25, 50, 75, 100 Das and at harvest, respectively. Results also concluded that the lowest number of branches plant^{-1} recorded from B_1 (control). The increasing trend of number of branches plant^{-1} is due to the fact that B helped in side branching and it also promoted the vegetative growth of peanut (Singaravel *et al*., 2006). Boron is important for root and shoots growth, flower fertility and responsible for the cell wall formation and stabilization. Boron is essential nutrient for nodule forming bacteria therefore, increased nodule count resulting in positive effect on biometric parameters of plants (Hirpara *et al*., 2019). The possible reason behind the finding might be that B helps to promote the vegetative growth of groundnut (Singaravel *et al*., 2006). The findings of this experiment conform to Sathya *et al.*, (2013), Verma *et al*., (2018) and Khuong *et al.*, (2022).

Combined application of calcium and boron showed significant variations on number of branches plant^{-1} at different levels of growth stages of groundnut (Table 3. and Appendix VII). Experimental data revealed that Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) produced the highest number of branches plant^{-1} and the lowest number of branches plant^{-1} produced from Ca_1B_1 (control) treatment. Das *et al*. (2016) also reported that boron and calcium applications significantly increased the plant height and number of branches of groundnut compared to that under no liming and boron application in acid soil of North East India. Cardoso *et al.* (2022), Galeriani *et al*. (2022), Kumar *et al*. (2022) and Kabir *et al*. (2013) also supported the findings of this experiment.



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 5. Effect of calcium on number of branches plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.07, 0.09, 0.16, 0.21 and 0.29 at 25, 50, 75, 100 DAS and at harvest, respectively).



Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 6. Effect of boron on number of branches plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.06, 0.13, 0.15, 0.19 and 0.16 at 25, 50, 75, 100 DAS and at harvest, respectively).

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

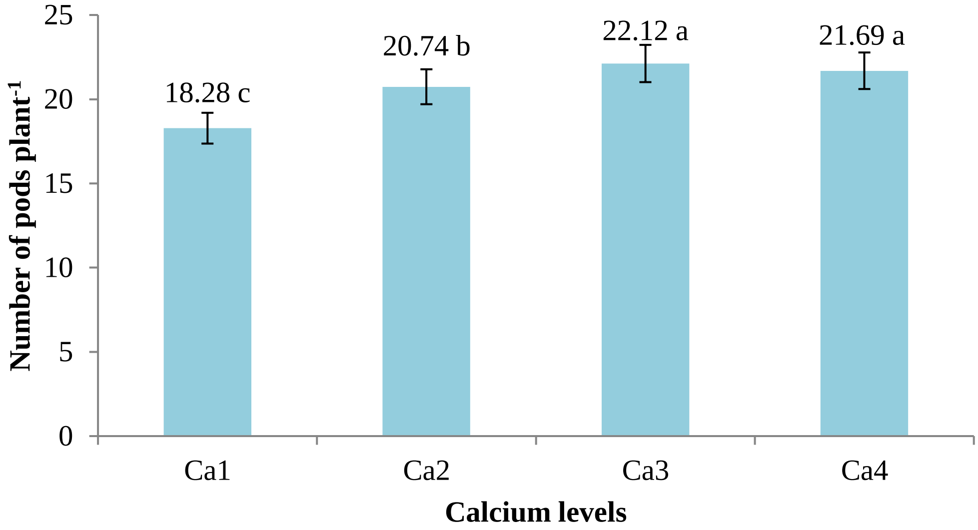
Treatment Combinations	Number of branches plant^{-1} at				
	25DAS	50 DAS	75 DAS	100DAS	Harvest
Ca_1B_1	2.00 h	4.33 i	5.67 h	6.00 i	5.33 j
Ca_1B_2	2.09 h	4.67 h	6.00 g	6.33 hi	5.75 i
Ca_1B_3	2.33 g	5.00 g	6.33 f	6.67 gh	6.33 gh
Ca_1B_4	2.33 g	4.83 gh	6.33 f	6.67 gh	6.00 hi
Ca_2B_1	2.42 fg	5.00 g	6.67 e	7.00 fg	6.33 gh
Ca_2B_2	2.50 f	5.33 f	6.67 e	7.00 fg	6.50 fg
Ca_2B_3	3.33 c	6.00 d	7.50 bc	8.00 cd	7.75 c
Ca_2B_4	3.33 c	6.00 d	7.33 c	7.75 d	7.33 d
Ca_3B_1	2.75 e	5.67 e	7.00 d	7.33 ef	6.75 ef
Ca_3B_2	3.00 d	5.83 de	7.33 c	7.67 de	7.33 d
Ca_3B_3	3.75 a	7.00 a	8.33 a	8.75 a	8.50 a
Ca_3B_4	3.50 b	6.50 c	7.67 b	8.33 bc	8.00 bc
Ca_4B_1	2.67 e	5.42 f	6.75 de	7.33 ef	6.75 ef
Ca_4B_2	3.00 d	5.75 e	7.00 d	7.33 ef	7.00 de
Ca_4B_3	3.67 a	6.75 b	7.67 b	8.67 ab	8.33 ab
Ca_4B_4	3.50 b	6.33 c	7.50 bc	8.00 cd	7.75 c
$LSD_{(0.05)}$	**0.12**	**0.26**	**0.29**	**0.38**	**0.31**
CV (%)	**2.50**	**2.79**	**2.49**	**3.04**	**2.72**

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, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}; Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}.

4.4. Effect of calcium and boron on number of pods plant^{-1} of groundnut

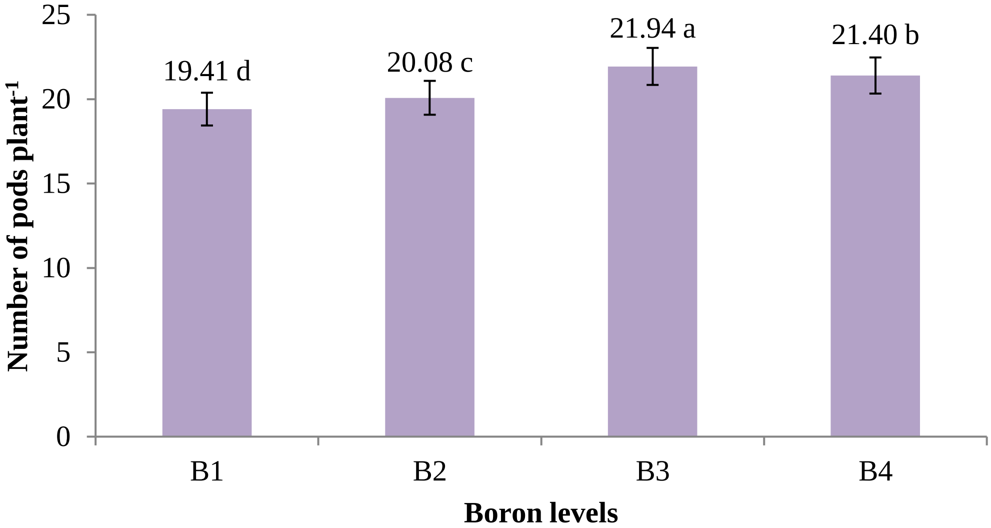
Different levels of calcium application had significant effect on number of pods plant^{-1} of groundnut (Figure 7 and Appendix VIII). Highest number of pods plant^{-1} 22.12 recorded from Ca_3 (60 kg Ca ha^{-1}) followed by Ca_4 (70 kg Ca ha^{-1}) treatment, which showed statistically similar result. Lowest number of pods plant^{-1} 18.28 recorded from Ca_1 treatment. Gypsum application increases the availability of sulphur and calcium to crops during the grand growth phase, resulting in improved pod growth and development. Calcium plays a major role in reproductive development of the groundnut crop, resulting in increasing pod yield (Ramya *et al*., 2022). According to Wiatrak *et al*. (2006) gypsum application aided to increase yield of groundnut with high potential yield by accumulative availability of Ca in the fruiting zone in strip-till management systems. They further clarified that yield of groundnut was higher after application of gypsum in comparison to plants without gypsum application. Increased crop productions by application of gypsum have also been reported in studies by Fernandes *et al*., (2007) and Rasouli *et al*., (2013). Kamara *et al*. (2011) also reported that the highest filled pods were obtained in the treatment with 100 kg Ca ha^{-1}.



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 7. Effect of calcium on number of pods plant^{-1} of groundnut ($LSD_{0.05}$ = 0.71; the same letters indicate that there is no significant difference between the meanings from LSD test).

Number of pods plant^{-1} of groundnut showed statistically significant variation with the application of different levels of boron (Figure 8 and Appendix VIII). Maximum number of pods plant^{-1} (21.94) recorded from B_3 (1.7 kg B ha^{-1}) treatment, which showed statistically significant differences with all other levels of boron application and the lowest number of pods plant^{-1} (19.41) recorded from control (B_1) treatment. Proper fertilization at early stages with NPK and B could be the reason for increasing the yield by different mechanisms. The improved nutritional management as a result of the increased supply of B and other nutrients might have influenced the chlorophyll, photosynthetic process and enzyme activity as well as grain formation (Poonguzhali *et al*., 2019). These are also involved in carbohydrate metabolism which increases the uptake of nutrients that ultimately results in increasing the yield (Tripathi and Hazra, 2003). When B was applied aerially substantial amount of it must have been transported to the reproductive organs thus developing the pods and increasing the pod and haulm yield subsequently (Sathya *et al.*, 2009). The findings of this experiment conform to Sathya *et al.,* (2013), Verma *et al.*, (2018) and Khuong *et al.*, (2022).

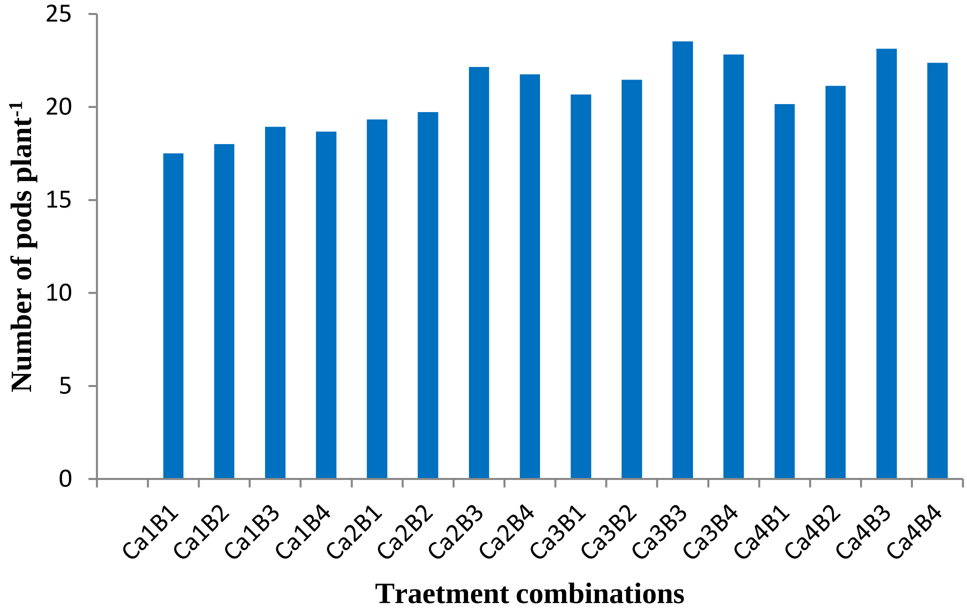


Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 8. Effect of boron on number of pods plant^{-1} of groundnut ($LSD_{0.05}$=0.46; the same letters indicate that there is no significant difference between the meanings from LSD test).

Different levels of calcium and boron application had significant effect on number of pods plant^{-1} of groundnut (Figure 9 and Appendix VIII). The highest number of pods plant^{-1} (23.53) recorded from Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment, which showed statistically similar results with Ca_3B_4 (60 kg Ca ha^{-1} + 2.125 kg B ha^{-1}) and Ca_4B_3 (70 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment. The lowest number of pods plant^{-1} (17.5) recorded from Ca_1B_1 (control) treatment. These may be due to provide adequate Ca availability in the fruiting zone, hence enhancing pod development (Chapman *et al.,* 1993). The increase in number of pods due to application boron might possibly through differentiation of tissue from somatic to reproductive and meristematic activity. In addition, the formation of floral clusters may have increased the number of flowers, which would have facilitated in pod formation (Khanna and Gupta, 2005). These findings were in consistent with the reports of other researchers

Cardoso *et al.*, (2022), Galeriani *et al*., (2022), Kumar *et al*., (2022) and Kabir *et al*., (2013).



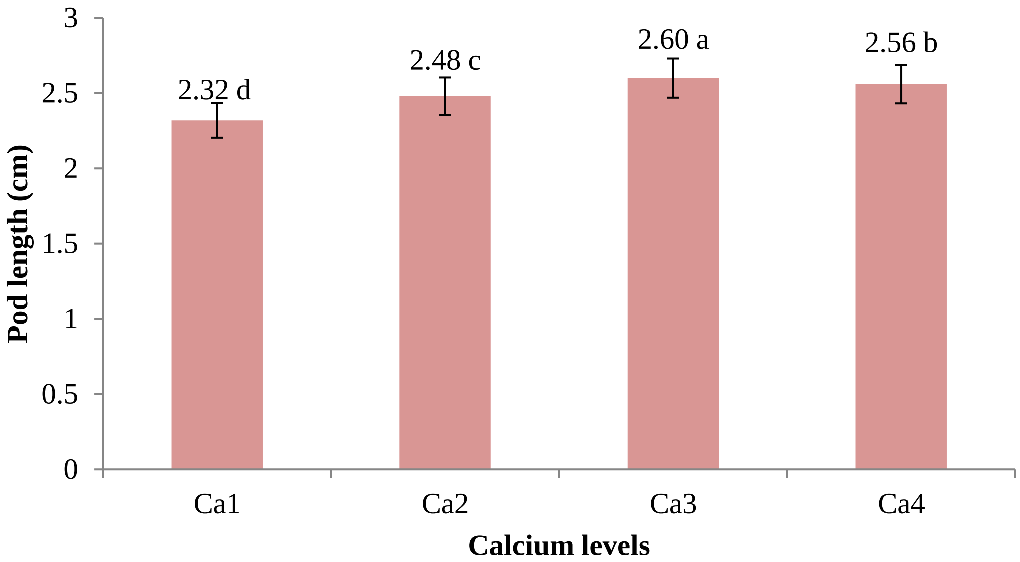
Here, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}; Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}.

Figure 9. Combined effect of calcium and boron on number of pods plant^{-1} of groundnut ($LSD_{0.05}$= 0.93; the same letters indicate that there is no significant difference between the meanings from LSD test).

4.5. Effect of calcium and boron on pod length (cm) of groundnut

Different levels of calcium application had significant effect on pod length of groundnut (Figure 10 and Appendix VIII). Highest pod length 2.60 cm recorded from Ca_3 (60 kg Ca ha^{-1}) treatment which showed statistically significant variation with all other treatments. Lowest pod length 2.32 cm recorded from Ca_1 (control) treatment. Application of gypsum improves crop availability of calcium and sulphur during the grand growth phase, leading to better pod growth and development. The reproductive growth of the groundnut crop is greatly influenced by calcium, which increases pod output (Ramya *et al*., 2022). According to Wiatrak *et al.* (2006), gypsum helped to boost groundnut yield in strip-till management methods due to the accumulation of Ca in the fruiting zone. They went on to say that compared to plants that didn't receive gypsum application, groundnut yield was higher with gypsum application. Increased crop productions by application of gypsum have also been reported in studies by

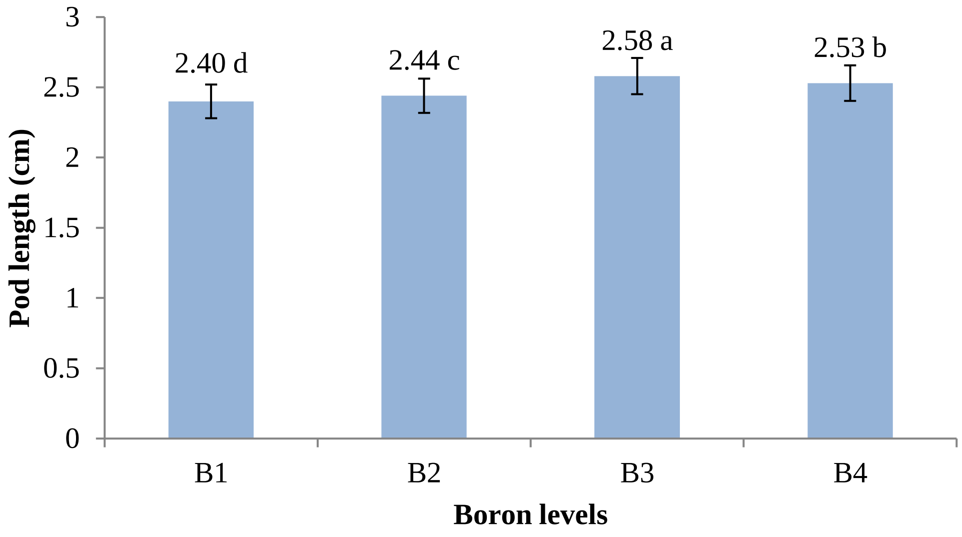
Fernandes *et al*., (2007) and Rasouli *et al*., (2013). Kamara *et al*. (2011) also reported that the highest filled pods were obtained in the treatment with 100 kg Ca ha^{-1}.



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 10. Effect of calcium on pod length of groundnut ($LSD_{0.05}$= 0.03; the same letters indicate that there is no significant difference between the meanings from LSD test).

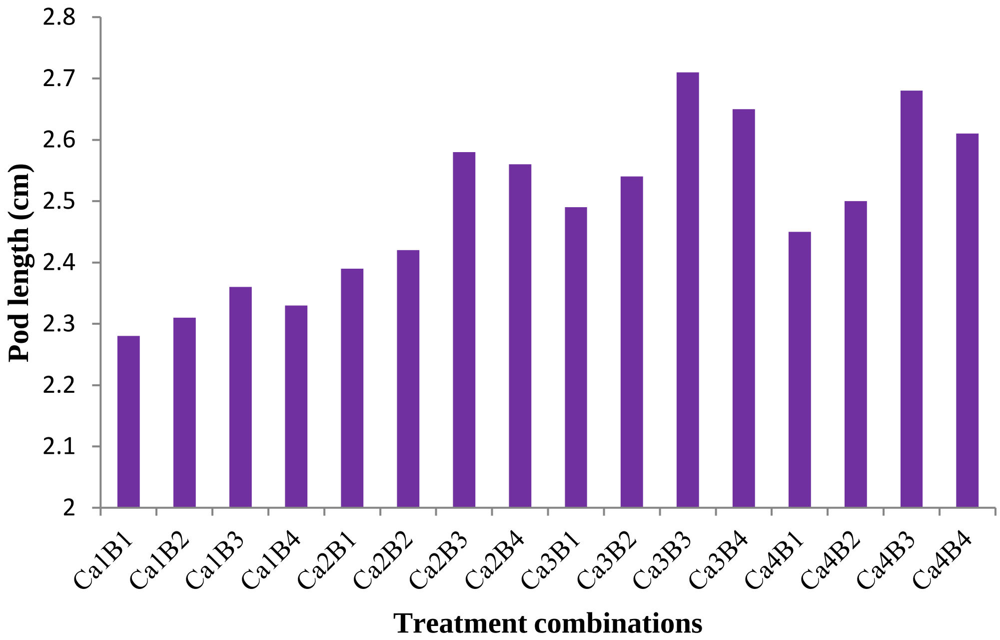
Pod length of groundnut showed statistically significant variation with the application of different levels of boron (Figure 11 and Appendix VIII). Maximum pod length (2.58 cm) recorded from B_3 (1.7 kg B ha^{-1}) treatment which showed statistically significant differences with all other levels of boron application and the lowest pod length (2.40 cm) recorded from control (B_1) treatment. The increased availability of B and other nutrients may have enhanced nutritional management, which may have increased grain formation by influencing the activity of enzymes, chlorophyll, and photosynthetic process (Poonguzhali *et al*., 2019). These are also involved in carbohydrate metabolism which increases the uptake of nutrients that ultimately results in increasing the yield (Tripathi and Hazra, 2003). When B was applied substantial amount of it must have been transported to the reproductive organs thus developing the pods and increasing the pod and haulm yield subsequently (Sathya *et al*., 2009). The findings of this experiment conform to Sathya *et al.*, (2013), Verma *et al*., (2018) and Khuong *et al*., (2022).



Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 11. Effect of boron on pod length of groundnut ($LSD_{0.05}$=0.03; the same letters indicate that there is no significant difference between the meanings from LSD test).

Different levels of calcium and boron application had significant effect on pod length (cm) of groundnut (Figure 12 and Appendix VIII). The highest pod length (2.71 cm) recorded from Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment which showed statistically similar results with Ca_4B_3 (70 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment. The lowest pod length (2.28 cm) recorded from Ca_1B_1 (control) treatment. These may be due to provide adequate Ca availability in the fruiting zone, hence enhancing pod development (Chapman *et al.*, 1993). The increase in pod length due to application boron might possibly through differentiation of tissue from somatic to reproductive and meristematic activity. In addition, the formation of floral clusters may have increased the number of flowers, which would have facilitated in pod formation (Khanna and Gupta, 2005). These findings were in consistent with the reports of other researchers Cardoso *et al.*, (2022), Galeriani *et al*., (2022), Kumar *et al*., (2022) and Kabir *et al*., (2013).

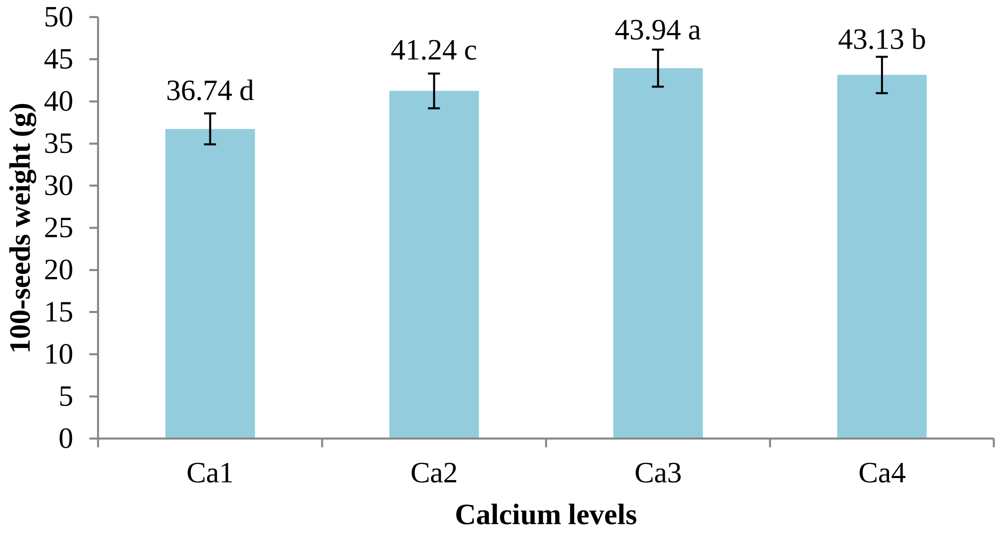


Here, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}; Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}.

Figure 12. Combined effect of calcium and boron on pod length (cm) of groundnut ($LSD_{0.05}$= 0.05; the same letters indicate that there is no significant difference between the meanings from LSD test).

4.6. Effect of calcium and boron on 100-seeds weight (g) of groundnut

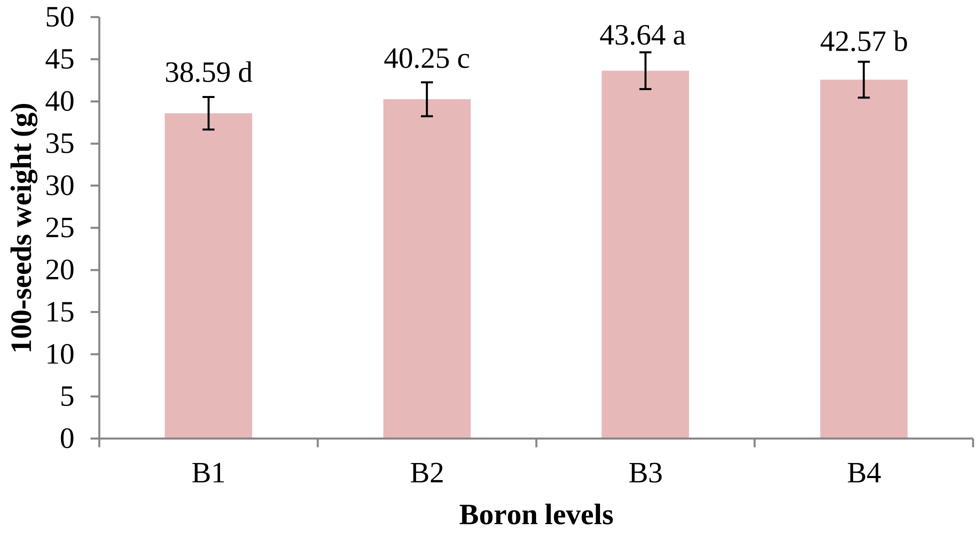
Different levels of calcium application had significant effect on 100-seeds weight of groundnut (Figure 13 and Appendix VIII). Maximum-100 seed weight (43.94 g) recorded from Ca_3 (60 kg Ca ha^{-1}) treatment and lowest 100-seeds weight (36.74 g) recorded from Ca_1 (control) treatment. This might be due to calcium present in the gypsum may lead to the production of big kernels through speedup of relative growth rate (RGR) of pods or enhance the production of photosynthetic materials which as result increase its transportation towards growing kernels (Jahanzaib *et al*., 2020). Increased 100-seeds weights of groundnut by application of gypsum have also been reported in studies by Fernandes *et al*., (2007) and Rasouli *et al*., (2013).



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 13. Effect of calcium on 100-seeds weight of groundnut ($LSD_{0.05}$=0.47; the same letters indicate that there is no significant difference between the meanings from LSD test).

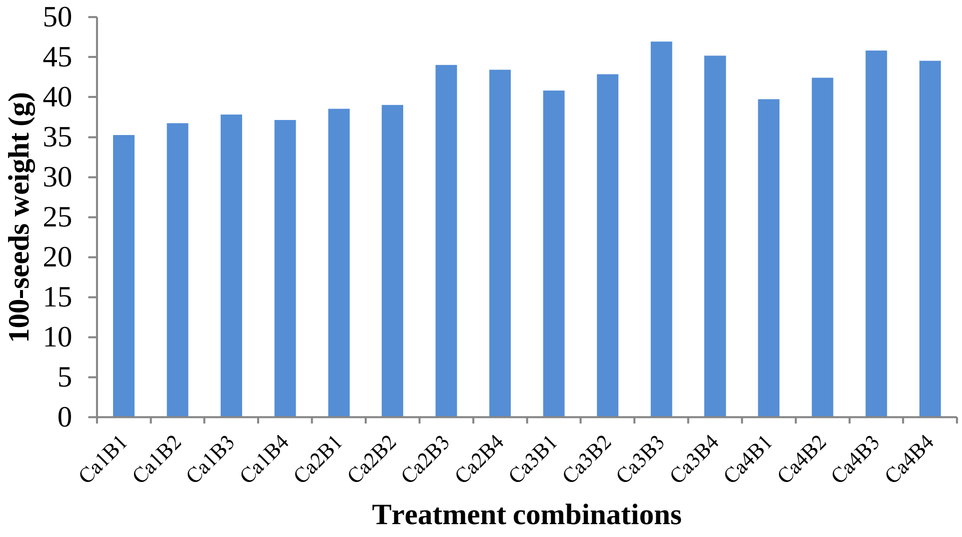
100-seeds weight of groundnut showed statistically significant variation with the application of different levels of boron (Figure 14 and Appendix VIII). Maximum 100-seeds weight (43.64 g) recorded from B_3 (1.7 kg B ha^{-1}) treatment which showed statistically significant differences with all other levels of boron application and the lowest 100-seeds weight (38.59 g) recorded from control (B_1) treatment. The increased availability of B and other nutrients may have enhanced nutritional management, which may have increased grain formation by influencing the activity of enzymes, chlorophyll, and photosynthetic process (Poonguzhali *et al*., 2019). These are also involved in carbohydrate metabolism which increases the uptake of nutrients that ultimately results in increasing the seed weight (Tripathi and Hazra, 2003). When B was applied substantial amount of it must have been transported to the reproductive organs thus developing the pods and increasing the pod and haulm yield subsequently (Sathya *et al*., 2009). The findings of this experiment conform to Sathya *et al.*, (2013), Verma *et al*., (2018) and Khuong *et al*., (2022).



Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 14. Effect of boron on 100-seeds weight of groundnut ($LSD_{0.05}$= 0.73; the same letters indicate that there is no significant difference between the meanings from LSD test).

Different levels of calcium and boron application had significant effect on 100-seeds weight (g) of groundnut (Figure 15 and Appendix VIII). The maximum 100-seeds weight (46.91 g) recorded from Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment which showed statistically similar results with Ca_4B_3 (70 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment. The minimum 100-seeds weight (35.27 g) recorded from Ca_1B_1 (control) treatment. These may be due to provide adequate Ca availability in the fruiting zone, hence enhancing pod development (Chapman *et al.*, 1993). The increase in pod length due to application boron might possibly through differentiation of tissue from somatic to reproductive and meristematic activity. In addition, the formation of floral clusters may have increased the number of flowers, which would have facilitated in pod formation (Khanna and Gupta, 2005). These findings were in consistent with the reports of other researchers Cardoso *et al.*, (2022), Galeriani *et al.*, (2022), Kumar *et al.*, (2022) and Kabir *et al.*, (2013).

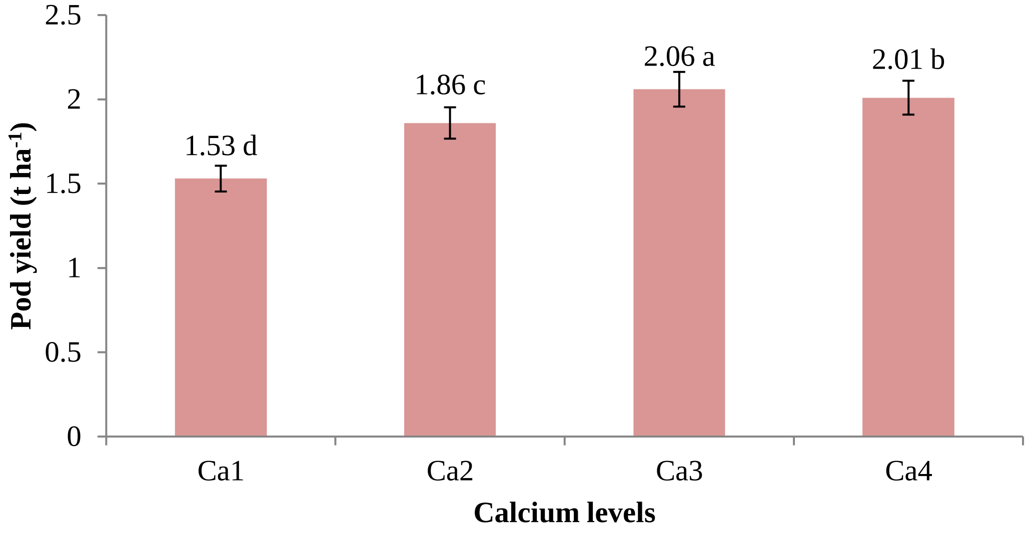


Here, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}; Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}.

Figure 15. Combined effect of calcium and boron on 100-seeds weight of groundnut ($LSD_{0.05}$= 1.47; the same letters indicate that there is no significant difference between the meanings from LSD test).

4.7. Effect of calcium and boron on pod yield (t ha^{-1}) of groundnut

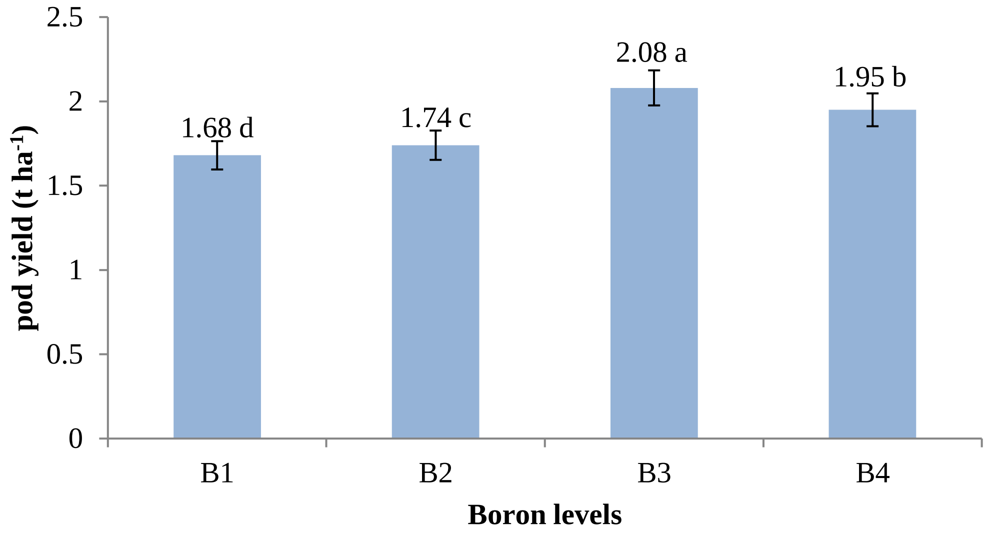
Pod yield (t ha^{-1}) showed significant variations due to different levels of calcium application (Figure 16 and Appendix IX). Results revealed that 60 kg Ca ha^{-1} (Ca_3) produced the highest pod yield (2.06 t ha^{-1}) which showed statistically significant variation with all other levels of calcium application. Results also revealed that the lowest pod yield (1.53 t ha^{-1}) recorded from Ca_1 (control) treatment. This may be due to accumulative availability of Ca in the fruiting zone of groundnut in strip-till management systems (Wiatrak *et al.*, 2006). Increased crop productions by application of gypsum have also been reported in studies by Fernandes *et al.*, (2007) and Rasouli *et al.*, (2013).



Here, Ca_1= 0 kg gypsum ha^{-1}, Ca_2= 250 kg gypsum ha^{-1}, Ca_3= 300 kg gypsum ha^{-1} and Ca_4= 350 kg gypsum ha^{-1}

Figure 16. Effect of calcium on pod yield (t ha^{-1}) of groundnut ($LSD_{0.05}$= 0.04; the same letters indicate that there is no significant difference between the meanings from LSD test).

Different levels of boron showed significant variations on pod yield (t ha^{-1}) of groundnut (Figure 17 and Appendix IX). Highest pod yield (2.08 t ha^{-1}) recorded from B_3 (1.7 kg B ha^{-1}) treatment and lowest pod yield (1.68 t ha^{-1}) recorded from B_1 (control) treatment. This might be due to when B was applied aerially substantial amount of it must have been transported to the reproductive organs thus developing the pods and increasing the pod and haulm yield subsequently (Sathya *et al*., 2009). The increased yield characters might be due to the involvement of B in producing growth promoting substances (Mekdad, 2019). Poonguzhali *et al*. (2019) reported that the increase in yield was due to the higher number of filled pods and least number of unfilled pods due to B application. The cumulative reduction in yield and growth attributes in control could be due to no B application. Sathya *et al.* (2013), Verma *et al*. (2018) and Khuong *et al.* (2022) supported the findings of this experiment.



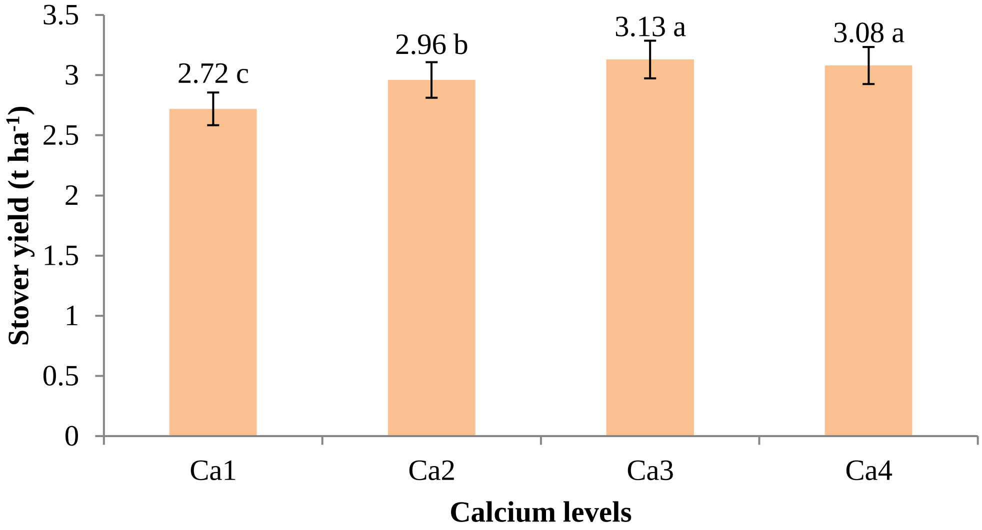
Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 17. Effect of boron on pod yield (t ha^{-1}) of groundnut ($LSD_{0.05}$= 0.06; the same letters indicate that there is no significant difference between the meanings from LSD test).

Pod yield (t ha^{-1}) of groundnut showed significant variations due to different levels of calcium and boron application (Table 4 and Appendix IX). The highest pod yield (2.35 t ha^{-1}) recorded from Ca_3B_3 treatment which showed statistically similar results with Ca_4B_3 treatment. The lowest pod yield (1.45 t ha^{-1}) recorded from Ca_1B_1 treatment. The betterment in yield characters might be ascribed to the effect of ca and B which enhanced the photosynthetic activity resulting in the production and accumulation of fats and essential fatty acids synthesis which enhanced the yield parameters and yield of groundnut (Kamaleshwaran *et al*., 2021). Chirwa *et al.* (2017) observed a positive interaction effect between Ca and B on improving the plant height. Cardoso *et al.* (2022), Galeriani *et al*. (2022), Kumar *et al*. (2022) and Kabir *et al*. (2013) also supported the findings of this experiment. Ramya *et al*. (2022) reported 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^{-1}), haulm yield (3345.13 kg ha^{-1}) and harvest index (44.43%) compared to all other treatment combinations.

4.8. Effect of calcium and boron on stover yield (t ha^{-1}) of groundnut

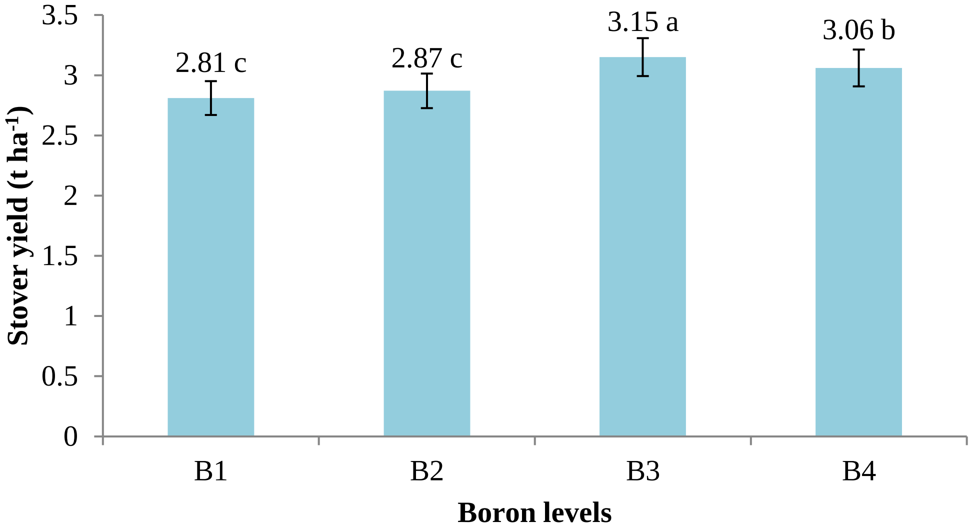
Different levels of calcium showed statistically significant variations on stover yield (t ha^{-1}) (Figure 18 and Appendix IX). Ca_3 (60 kg Ca ha^{-1}) application showed highest stover yield (3.13 t ha^{-1}) of groundnut which showed statistically similar results with Ca_4 (70 kg Ca ha^{-1}). The lowest stover yield (2.72 t ha^{-1}) recorded with Ca_1 (control) treatment. This might be due to application of gypsum was attributed to concomitant influence of Sulphur released from the gypsum on availability of other nutrients from the soil and their extraction by the plant seems to have provided congenial nutritional environment for the plants (Sagar *et al*., 2020). Calcium plays a major role in reproductive development of the groundnut crop, resulting in increasing stover yield (Ramya *et al*., 2022). Increased stover yield by application of gypsum have also been reported in studies by Fernandes *et al*., (2007) and Rasouli *et al*., (2013).



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 18. Effect of calcium on stover yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.06; the same letters indicate that there is no significant difference between the meanings from LSD test)

Significant variation of stover yield (t ha^{-1}) was revealed due to different level of boron application (Figure 19 and Appendix IX). The maximum stover yield (3.15 t ha^{-1}) recorded from B_3 (1.7 kg B ha^{-1}) application and lowest stover yield recorded from B_1 (control) treatment. The improvement in biomass yield of groundnut may be attributed to the complementary role of boron in the reproduction and vegetative stages of plants. Boron also involved in carbohydrate metabolism which increases the uptake of nutrients that ultimately results in increasing the yield. The carbohydrate metabolism may be an additional reason through the increased transformation of photosynthesis towards yield. Singh *et al*. (2008) reported that application of B has pronounced influence on flowering and yield attributes such as shelling percentage and 100 seed weight in groundnut. Sathya *et al.* (2013), Verma *et al.* (2018) and Khuong *et al.* (2022) supported the findings of this experiment.



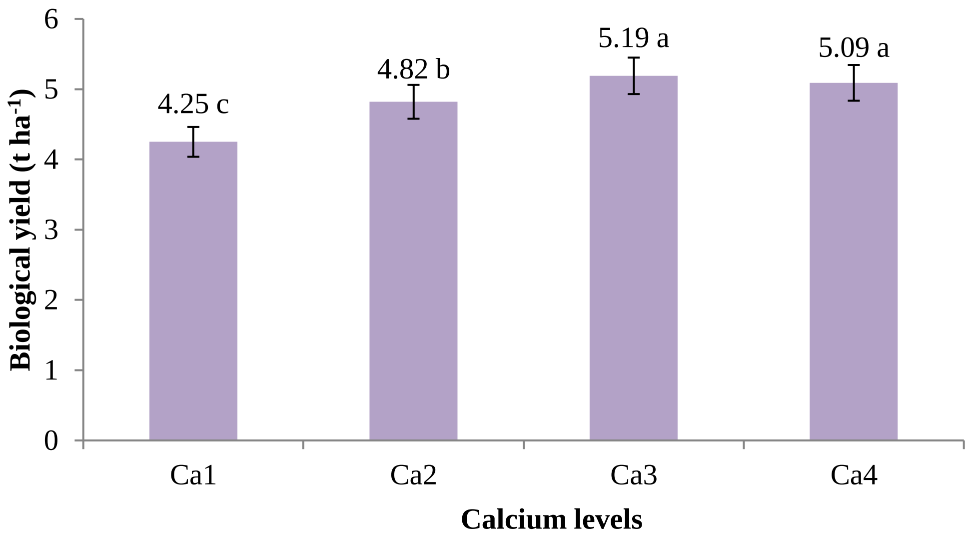
Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 19. Effect of boron on stover yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.06; the same letters indicate that there is no significant difference between the meanings from LSD test).

Stover yield (t ha^{-1}) of groundnut showed significant variations with the combined application of calcium and boron (Table 4 and Appendix IX). The highest stover yield 3.37 t ha^{-1} recorded from Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment which showed statistically similar results with Ca_3B_4 (60 kg Ca ha^{-1} + 2.125 kg B ha^{-1}) and Ca_4B_3 (70 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment. The lowest stover yield (2.65 t ha^{-1}) recorded from Ca_1B_1 (control) treatment. The increase in haulm yield might be due to the synergistic effect of boron and calcium due to utilization of large quantities of nutrients through their well-developed root system and nodules which might have resulted in both plant development and ultimate straw yield at maturity (Ramya and Singh, 2022). These findings were in consistent with the reports of other researchers Cardoso *et al*., (2022), Galeriani *et al*., (2022), Kumar *et al*., (2022) and Kabir *et al*., (2013).

4.9. Effect of calcium and boron on biological yield (t ha^{-1}) of groundnut

Biological yield (t ha^{-1}) of groundnut showed statistically significant variations with different level of calcium application (Figure 20 and Appendix IX). The maximum biological yield 5.19 t ha^{-1} observed with Ca_3 (60 kg Ca ha^{-1}) treatment and lowest biological yield 4.25 t ha^{-1} with Ca_1 (control) treatment. Gypsum fertilization of the crop, which leads to an increase in haulm and kernel yield, was attributed to a concomitant influence of calcium released from gypsum and the availability of other nutrients from the soil and their extraction by the plant, which appears to have provided the plants with a favorable nutritional environment and increasing the biological yield (Ramya and Singh, 2022). Kamara *et al.* (2017) and Das *et al.* (2015) supported the findings of this experiment and reported that different levels of gypsum had significant effect on growth and yield of groundnut.

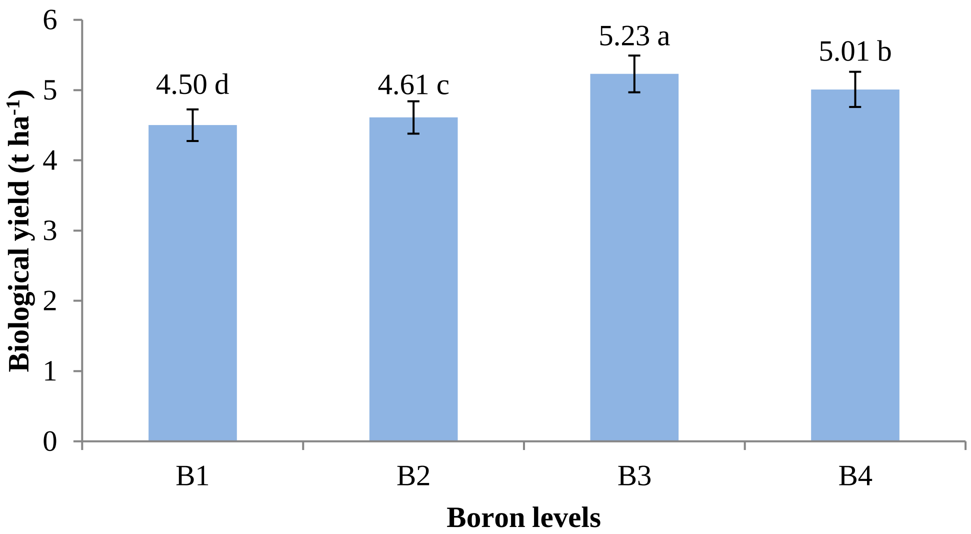


Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 20. Effect of calcium on biological yield (t ha^{-1}) of groundnut ($LSD_{0.05}$= 0.12; the same letters indicate that there is no significant difference between the meanings from LSD test).

Different levels of boron application showed statistically significant variations on biological yield (t ha^{-1}) of groundnut (Figure 21 and Appendix IX). The highest biological yield 5.23 t ha^{-1} recorded with B_3 (1.7 kg B ha^{-1}) treatment followed by B_4 (2.125 kg B ha^{-1}) and the lowest biological yield 4.50 t ha^{-1} with B_1 (control) treatment. This might be due to boron increased nitrogen fixation which affects plant growth rate and metabolism which results in higher biological yields (Bhagiya *et al.*, 2005). The findings of this experiment conform to Sathya *et al.*, (2013), Verma *et al.*, (2018) and Khuong *et al.*, (2022).

Different levels of calcium and boron combined application showed statistically significant variations on biological yield (t ha-1) of groundnut (Table 4 and Appendix IX). The highest biological yield 5.72 t ha^{-1} recorded with Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment which showed statistically identical results with Ca_4B_3 (70 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment and the lowest biological yield 4.10 t ha^{-1} recorded with Ca_1B_1 (control) treatment. Because of their efficient use of large amounts of nutrients through their well-developed root systems and nodules, the boron and calcium compounds may have contributed to the increase in biological yield. This development may have led to the development of the plants and the eventual yield of straw at maturity (Ramya and Singh, 2022). These findings were in consistent with the reports of other researchers Cardoso *et al.*, (2022), Galeriani *et al.*, (2022), Kumar *et al.*, (2022) and Kabir *et al.*, (2013).

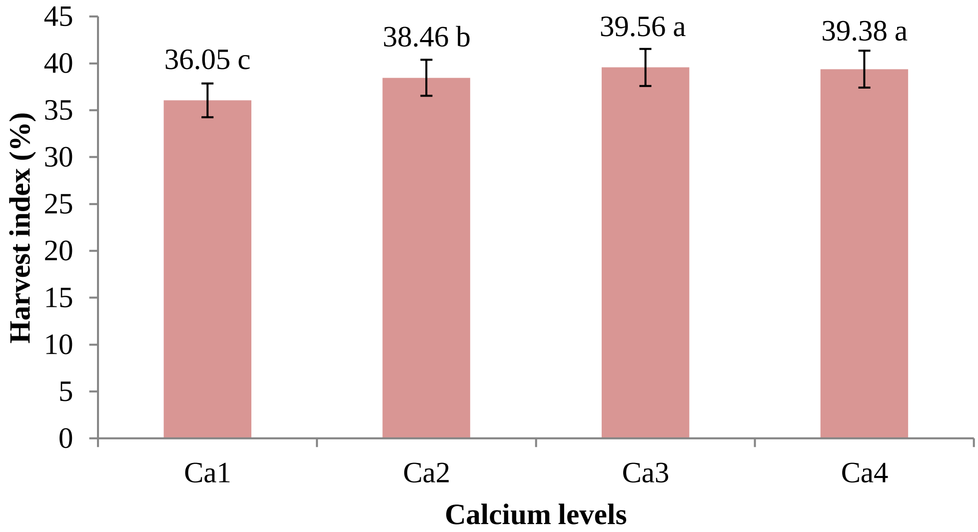


Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 21. Effect of boron on biological yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.09; the same letters indicate that there is no significant difference between the meanings from LSD test).

4.10. Effect of calcium and boron on harvest index (%) of groundnut

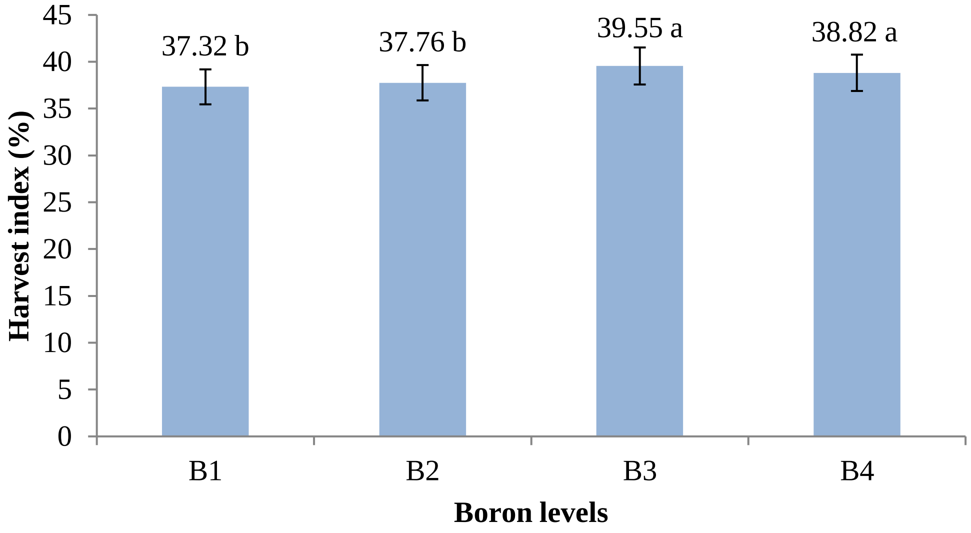
Significant variation was obtained on harvest index (%) due to the different levels of calcium application (Figure 22 and Appendix IX). Experiment results concluded that Ca_3 (60 kg Ca ha^{-1}) and Ca_4 (70 kg Ca ha^{-1}) treatment showed statistically identical results on harvest index. The highest harvest index (39.56 %) recorded with Ca_3 (60 kg Ca ha^{-1}) treatment and the lowest harvest index (36.05 %) recorded with Ca_4 (70 kg Ca ha^{-1}) treatment. The highest harvest index recorded from Crop yields have been linked to an increase in calcium application (Caires *et al.*, 2008). Furthermore, the interaction effect of calcium on N and P may improve the chlorophyll content, stomatal conductance and quantum yield of photosystem II resulting in higher crop yield (Zangani *et al.*, 2021). Inban *et al*. (2022), Kamara *et al.* (2017), Yadav *et al.* (2015) and other researchers supported the findings of this experiment.



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 22. Effect of calcium on harvest index of groundnut ($LSD_{0.05}$= 0.86; the same letters indicate that there is no significant difference between the meanings from LSD test).

Significant variation was observed in harvest index (%) of groundnut due to application of boron (Figure 23 and Appendix IX). The maximum harvest index (39.55 %) was found due to application of 1.7 kg B ha^{-1} (B_3) and the minimum harvest index was found due to application of 0 kg boric acid ha^{-1} (B_1). Kumar *et al.* (2020) stated that boron significantly increased the chlorophyll content and photosynthetic leaf intensity, increased plant dry matter accumulation, early flowering and promoted the transport of photosynthates from vegetative organs to the reproductive organs, resulting in a significant increase in groundnut yield. It was observed that the increase in yield parameters was due to a greater number of filled pods and the least number of unfilled pods due to boron application (Ansari *et al.,* 2013) Similar positive results on effect of boron on groundnut harvest index reported by Haneena *et al*., (2021), Hossain *et al*., (2021) and Nandi *et al*., (2020).



Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 23. Effect of boron on harvest index of groundnut ($LSD_{0.05}$= 0.79; the same letters indicate that there is no significant difference between the meanings from LSD test).

Different levels of calcium and boron combined application showed statistically significant variations on harvest index (%) of groundnut (Table 4 and Appendix IX). The highest harvest index 41.08 % recorded with Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment which showed statistically identical results with Ca_4B_3 (70 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) and Ca_3B_4 (60 kg Ca ha^{-1} + 2.125 kg B ha^{-1}) treatment. The lowest harvest index 35.37 % recorded with Ca_1B_1 (control) treatment. Calcium aids in peg penetration by loosening the soil, resulting in the creation of more pods in the groundnut. On the other hand, the increase in yield was attributed to the higher number of filled pods and the least number of unfilled pods due to Boron application (Poonguzhali *et al.*, 2019).

4.11. Effect of calcium and boron on germination (%) of groundnut

Different levels of calcium showed significant variations on germination (%) of groundnut (Figure 24 and Appendix X). Treatment Ca_3 (60 kg Ca ha^{-1}) and Ca_4 (70 kg Ca ha^{-1}) showed statistically identical results on germination (%) of groundnut. The highest germination 87.09 % recorded with Ca_3 (60 kg Ca ha^{-1}) treatment followed by Ca_4 (70 kg Ca ha^{-1}). The lowest germination 79.83 % obtained with Ca_1 (control) treatment. Calcium is crucial for the formation of cell walls (Marschner, 1995), unfilled pods (Smith, 1954), darker seed plumules (Cox and Reid, 1964), and decreased germination (Harris and Brolmann, 1966) can all be caused by insufficient Ca uptake during development. Kamara *et al.* (2017) concluded that increased calcium fertilization increased the vigour, germination and oil content of the seeds of the groundnut. Kirthisinghe *et al.* (2014), Gashti *et al.* (2012) and Rajanarasimha *et al.* (2021) supported the findings of this experiment.

Germination (%) of groundnut showed significant variation due to different levels of boron application (Figure 25 and Appendix X). The highest germination 86.88 % obtained with B_3 (1.7 kg B ha^{-1}) and the lowest germination 81.83 % obtained with B_1 (control) treatment. Quamruzzaman *et al.* (2016) revealed that days to first-last emergence and days to first-50% flowering took shorter times and vegetative growth, pods dry weight $plant^{-1}$, pod yield, and germination were markedly increased with the application of boron. This might be due to that boron helped to get viable seed (Roekkasem, 1994). Nandi *et al*. (2020), Sonwane *et al*. (2010) and Nasef *et al*. (2006) also supported the findings of this experiment.

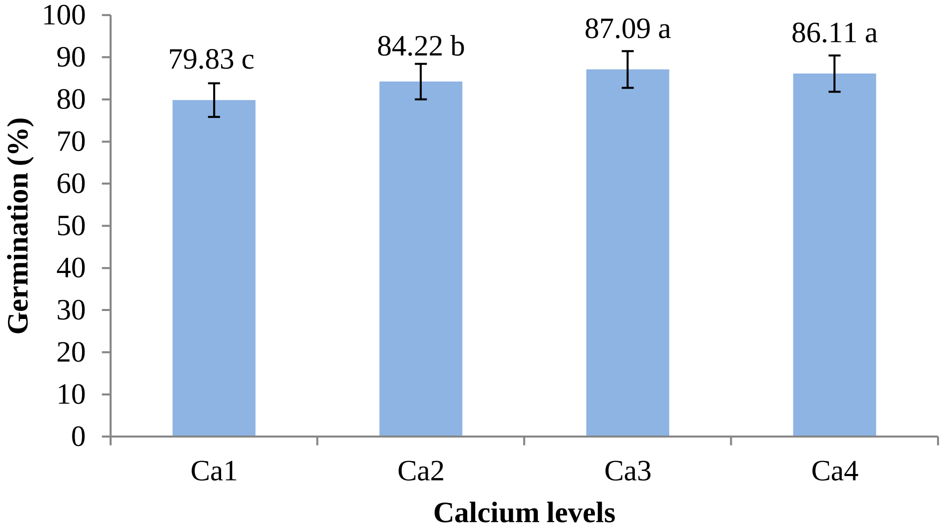
Combined application of calcium and boron showed significant variations on germination (%) of groundnut (Table 5 and Appendix X). The maximum germination 90.50 % recorded with Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) and the minimum germination 78.80 % obtained with Ca_1B_1 control). Mansingh *et al.* (2022) reported that Ca @ 150 kg ha^{-1} and B 1.5 kg ha^{-1} was proved to be the most effective in improving growth and yield characteristics of groundnut. This might be due to strong synergistic relationship among calcium and boron. Jena *et al.* (2009), Chirwa *et al.* (2017) and Wen-Xin *et al.* (2001) supported the findings of this experiment

Table 4. Combined Effect of calcium and boron on pod yield, stover yield, biological yield and harvest index of groundnut

Treatment Combinations	Pod yield ($t\ ha^{-1}$)	Stover yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
Ca_1B_1	1.45 l	2.65 k	4.10 l	35.37 i
Ca_1B_2	1.50 l	2.69 jk	4.19 kl	35.80 i
Ca_1B_3	1.62 jk	2.79 h-j	4.41 ij	36.73 g-i
Ca_1B_4	1.56 kl	2.74 i-k	4.30 jk	36.28 hi
Ca_2B_1	1.70 ij	2.83 g-i	4.53 hi	37.52 f-h
Ca_2B_2	1.73 ij	2.86 gh	4.59 g-i	37.69 e-h
Ca_2B_3	2.05 de	3.14 cd	5.19 d	39.49 a-d
Ca_2B_4	1.95 ef	3.03 de	4.98 e	39.16 b-e
Ca_3B_1	1.80 g-i	2.90 f-h	4.70 gh	38.30 c-g
Ca_3B_2	1.90 fg	2.99 ef	4.89 ef	38.85 b-f
Ca_3B_3	2.35 a	3.37 a	5.72 a	41.08 a
Ca_3B_4	2.18 bc	3.27 ab	5.45 bc	40.00 ab
Ca_4B_1	1.78 hi	2.89 f-h	4.67 gh	38.11 d-g
Ca_4B_2	1.85 f-h	2.93 e-g	4.78 fg	38.70 b-f
Ca_4B_3	2.29 ab	3.31 ab	5.60 ab	40.89 a
Ca_4B_4	2.12 cd	3.20 bc	5.32 cd	39.85 a-c
$LSD_{(0.05)}$	**0.11**	**0.11**	**0.17**	**1.59**
CV (%)	**3.79**	**2.30**	**2.19**	**2.46**

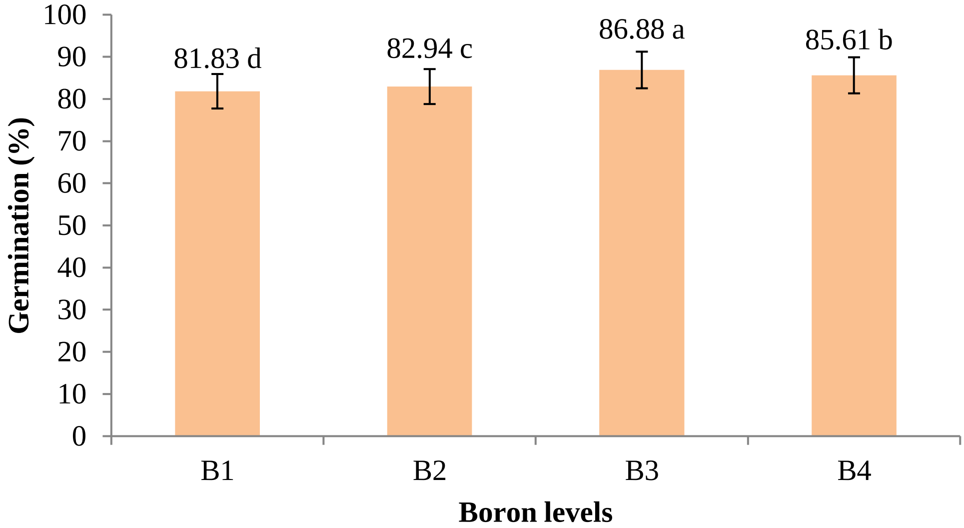
In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Here, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}; Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}.



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 24. Effect of calcium on germination (%) of groundnut ($LSD_{0.05}$= 1.55; the same letters indicate that there is no significant difference between the meanings from LSD test).



Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

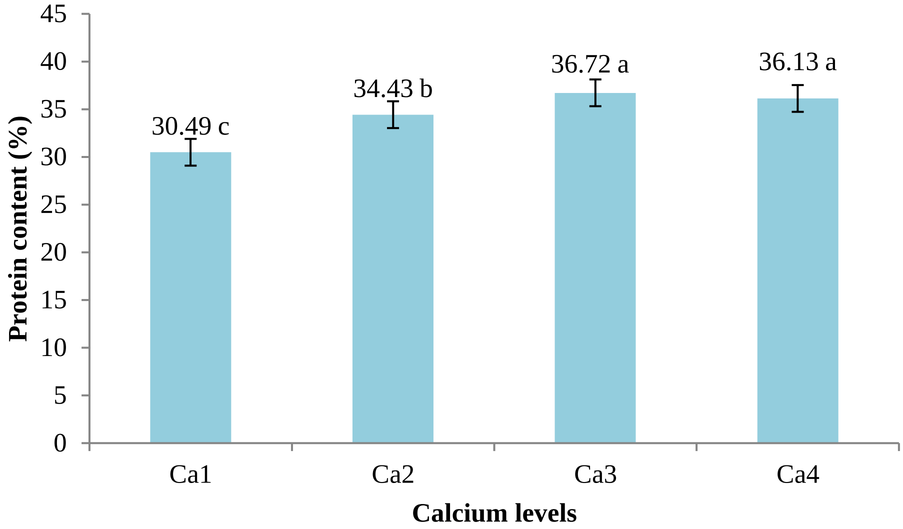
Figure 25. Effect of boron on germination (%) of groundnut ($LSD_{0.05}$= 1.05; the same letters indicate that there is no significant difference between the meanings from LSD test).

4.12. Effect of calcium and boron on protein content (%) of groundnut

Protein content (%) of groundnut exerted significant variation among the different calcium levels (Figure 26 and Appendix X). The results concluded that the highest protein content (36.72 %) obtained from Ca_3 (60 kg Ca ha^{-1}) treatment which showed statistically identical results with Ca_4 (70 kg Ca ha^{-1}) treatment. The lowest protein content (30.49 %) recorded from Ca_1 (control) treatment. Gypsum fertilization has a good impact on plants because it improves the nutrient environment in the rhizosphere and throughout the plant system, causing N, P, and S to move to reproductive regions and, as a result, rise in concentration in the kernel, which aids in protein synthesis (Alcordo and Rechcigl, 1993). Ullah *et al.* (2019) also supported the findings of this experiment and reported that the effect of gypsum on nitrogen and protein contents of groundnut straw and nut was directly proportional to gypsum dose.

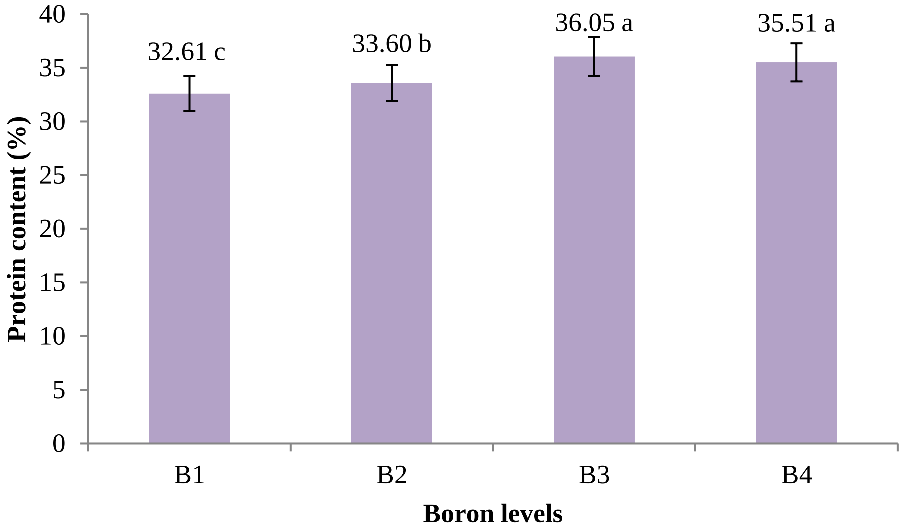
Protein content (%) of groundnut exerted significant variation among the different levels of boron (Figure 27 and Appendix X). The maximum protein content 36.05 % obtained from 1.7 kg B ha^{-1} (B_3) application and minimum protein content 32.61 % obtained from control or no boron application (B_1). Haneena *et al*. (2021) concluded that protein content, boron content and uptake of micronutrients *viz*., iron, zinc, manganese, copper and boron were significantly improved with the application of boron in groundnut. This might be due to boron has significant influence in the protein and nucleic acid metabolism, maintaining the structural integrity of the plant and protects plasma membrane from external damage, improves root growth and nodulation in leguminous plants, thus stimulates nitrogen content and that might increase protein synthesis and subsequent storage of protein. Poonguzhali *et al*. (2019) supported the significant increase in protein content with application of boron in groundnut.

Different levels of calcium and boron combine application showed significant variation on protein content (%) of groundnut (Table 5 and Appendix X). The maximum 38.72 % protein content obtained from CA_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment and the minimum 29.50 % protein content obtained from Ca_1B_1 (control) treatment. This may be due to strong synergistic effect among calcium and boron, which helps plant growth and development properly and ultimately increase protein content in groundnut kernel (Jena *et al*., 2009). Ramya and Singh (2022) also supported the findings of this experiment.



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 26. Effect of calcium on protein content of groundnut ($LSD_{0.05}$= 1.21; the same letters indicate that there is no significant difference between the meanings from LSD test).



Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 27. Effect of boron on protein content of groundnut ($LSD_{0.05}$= 0.65; the same letters indicate that there is no significant difference between the meanings from LSD test).

4.13. Effect of calcium and boron on oil content (%) of groundnut

Oil content (%) of groundnut showed statistically significant variation with the application of different levels of calcium (Figure 28 and Appendix 10). The maximum oil content 43.67 % obtained with the application of Ca_3 (60 kg Ca ha^{-1}) followed by

Ca_4 (70 kg Ca ha^{-1}) which showed statistically identical results. The minimum oil content 33.76 % recorded from Ca_1 (control). The concurrent rise in oil content may have been caused by greater calcium application, which boosted photosynthetic material synthesis (Yadav *et al*., 2015). Hasan and Mahmoud (2014) also supported the findings of this experiment.

Different levels of boron application showed significant variations on oil content (%) of groundnut (Figure 29 and Appendix X). Experiment results concluded that the highest oil content 43.28 % obtained from B_3 (1.7 kg B ha^{-1}) and the lowest oil content 36.31 % obtained from B_1 (control). Haneena *et al.* (2021) concluded that the increase in oil content may be because of role of boron in the synthesis of essential amino acids, protein and lipids that acts as an electron carrier in the photosynthetic process required for production of oil. Boron also has a positive role on the enhancement of oil content perhaps due to the indirect effect on the synthesis of fat. Rabichandra *et al.* (2015) also supported the findings of this experiment and reported that boron application increase oil content in groundnut seed.

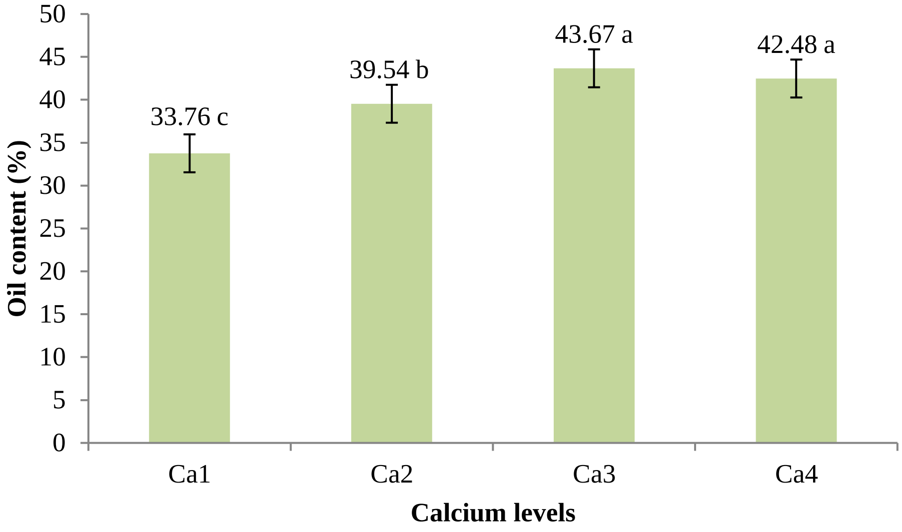
Combined application of calcium and boron showed significant variation on Oil content of groundnut (Table 5 and Appendix X). The highest oil content 47.90 % recorded from Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) and lowest 32.25 % from Ca_1B_1 (control) treatment combinations. Because of their efficient use of large amounts of nutrients through their well-developed root systems and nodules, the boron and calcium compounds may have contributed to the increase oil content in groundnut seed (Mansing *et al*., 2022). Rathod *et al.* (2017) and Kabir *et al.* (2013) also supported the findings of this study.

4.14. Effect of calcium and boron on vitamin E content (mg/100g seed) of groundnut

Vitamin E content (mg/100g seed) showed significant variations with the application of different level of calcium (Figure 30 and Appendix X). The maximum vitamin E content 8.37 mg/100g seed recorded from Ca_3 (60 kg Ca ha^{-1}) application which showed statistically similar results from Ca_4 (70 kg Ca ha^{-1}) treatment. The lowest vitamin E 5.42 mg/100g seed obtained from Ca_1 (control) treatment. This might be due to calcium is the most critical element in the development of pods and seeds of groundnut (Vishkaei, 1999).

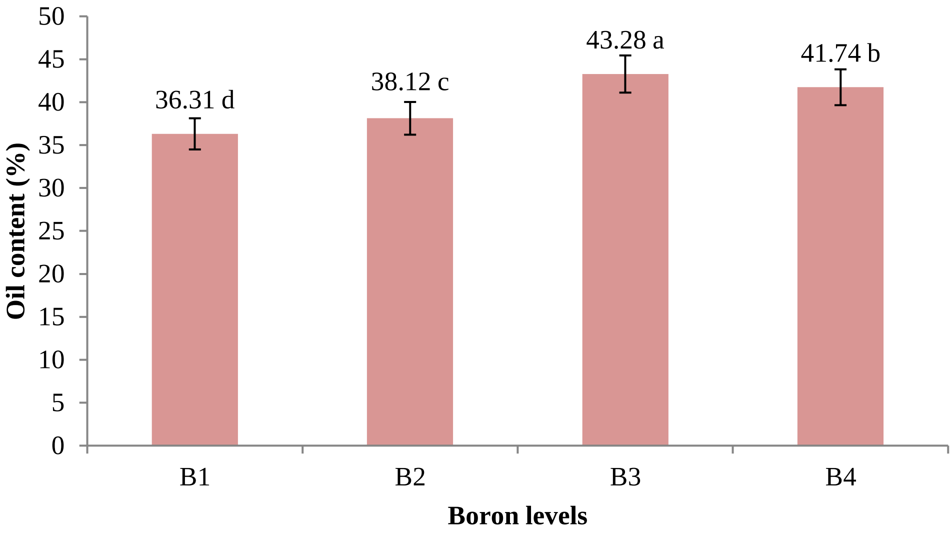
Application of different levels of boron showed significant variations on vitamin E content of groundnut (Figure 31 and Appendix X). The maximum vitamin E 8.32 mg/100 g seed obtained from B_3 (1.7 kg B ha^{-1}) and the lowest vitamin E content 6.26 mg/100 g seed obtained from B_1 (control) treatment. The possible reason behind the finding might be that boron helped to uptake the highest value of N, P, K, Fe and Mn in plant and seed of groundnut which helps to ensure proper growth and quality (Nasef *et al*., 2006). Verma *et al*. (2018), Ganie *et al*. (2014) also supported the findings of this study.

Combined application of calcium and boron showed significant variations on vitamin E content of groundnut seed (Table 5 and Appendix X). The maximum vitamin E content 9.68 mg/100g seed recorded with the application of Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) which showed statistically similar results with Ca_3B_4 (60 kg Ca ha^{-1} + 2.125 kg B ha^{-1}) and Ca_4B_3 (70 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment. The minimum vitamin E content 4.95 mg/100g seed recorded with Ca_1B_1 (control) treatment. The possible reason behind the finding might be that calcium and boron helped to uptake the highest value of N, P, K, Fe and Mn and availability of all important nutrients on soil improved the nutritional status of kernel of groundnut (Rathod *et al*., 2017). Ramya *et al.* (2022) also supported the findings of this study and reported that the application of 400 kg ha^{-1} gypsum and 10 kg boron ha^{-1} improved plant growth and yield indices, as well as improved groundnut crop economics.



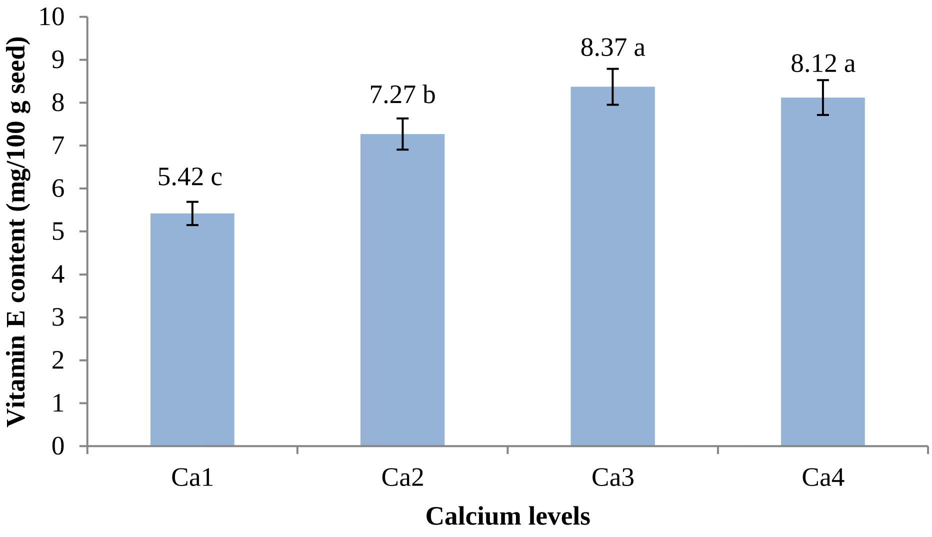
Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 28. Effect of calcium on oil content of groundnut ($LSD_{0.05}$= 1.36; the same letters indicate that there is no significant difference between the meanings from LSD test).



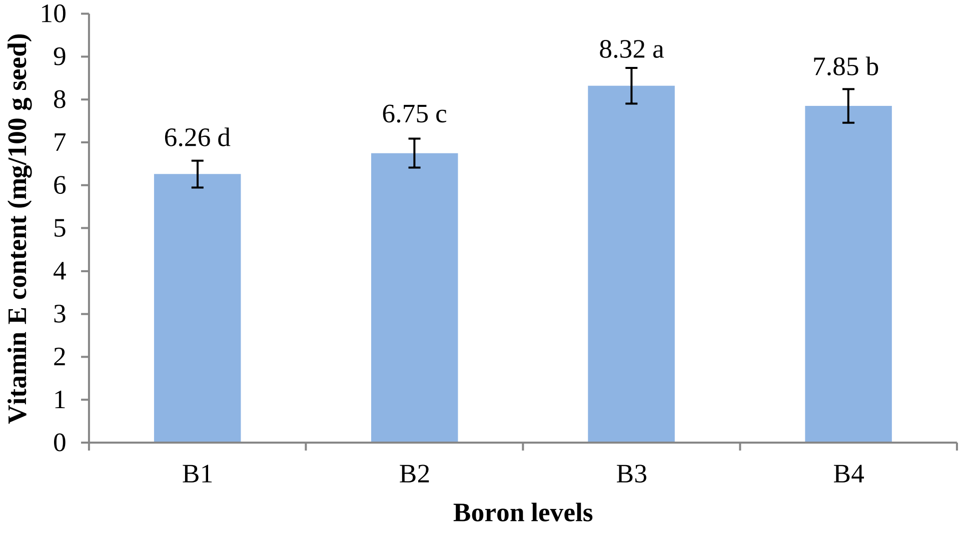
Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}

Figure 29. Effect of boron on oil content of groundnut ($LSD_{0.05}$= 1.28; the same letters indicate that there is no significant difference between the meanings from LSD test).



Here, Ca_1= 0 kg Ca ha^{-1}, Ca_2= 50 kg Ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}

Figure 30. Effect of calcium on vitamin E content of groundnut ($LSD_{0.05}$= 0.46; the same letters indicate that there is no significant difference between the meanings from LSD test).



Here, B_1= 0 kg boric acid ha^{-1}, B_2= 7.50 kg boric acid ha^{-1}, B_3= 10 kg boric acid ha^{-1} and B_4= 12.50 kg boric acid ha^{-1}

Figure 31. Effect of boron on vitamin E content of groundnut ($LSD_{0.05}$= 0.36; the same letters indicate that there is no significant difference between the meanings from LSD test).

Table 5. Combined effect of calcium and boron on germination percentage, protein content, oil content and vitamin E content of groundnut

Treatment Combinations	Germination (%)	Protein content (%)	Oil content (%)	Vitamin E content (mg/100g seed)
Ca_1B_1	78.80 k	29.50 j	32.25 k	4.95 j
Ca_1B_2	79.75 jk	30.47 ij	33.67 jk	5.27 ij
Ca_1B_3	80.60 h-k	30.85 hi	34.95 h-j	5.81 i
Ca_1B_4	80.20 i-k	31.15 hi	34.18 i-k	5.65 ij
Ca_2B_1	81.90 g-j	32.35 gh	35.71 h-j	6.00 hi
Ca_2B_2	82.20 g-i	32.92 g	36.44 hi	6.62 gh
Ca_2B_3	86.80 b-d	36.45 b-d	43.46 c-e	8.45 cd
Ca_2B_4	86.00 c-e	36.00 c-e	42.58 de	8.00 de
Ca_3B_1	83.90 e-g	34.75 ef	39.72 fg	7.15 fg
Ca_3B_2	85.20 c-e	35.67 c-e	41.50 ef	7.67 ef
Ca_3B_3	90.50 a	38.72 a	47.90 a	9.68 a
Ca_3B_4	88.75 ab	37.75 ab	45.55 a-c	8.97 a-c
Ca_4B_1	82.75 f-h	33.87 fg	37.55 gh	6.94 fg
Ca_4B_2	84.60 d-f	35.35 de	40.87 ef	7.42 ef
Ca_4B_3	89.60 a	38.18 a	46.82 ab	9.32 ab
Ca_4B_4	87.50 bc	37.15 a-c	44.67 b-d	8.81 bc
$LSD_{(0.05)}$	**2.09**	**1.30**	**2.57**	**0.72**
CV(%)	**1.47**	**2.25**	**3.83**	**5.87**

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, Ca_1= 0 kg Ca ha^{-1} (control), Ca_2= 50 kg ca ha^{-1}, Ca_3= 60 kg Ca ha^{-1} and Ca_4= 70 kg Ca ha^{-1}; Here, B_1= 0 kg B ha^{-1} (control), B_2= 1,275 kg B ha^{-1}, B_3= 1.7 kg B ha^{-1} and B_4= 2.125 kg B ha^{-1}.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh the period of March to July, 2021 to study the effect of calcium and boron on yield and seed quality of groundnut *cv.* BARI Chinabadam-10. The experimental field belongs to the Agro-ecological zone (AEZ) of "The Modhupur Tract", AEZ-28. The soil of the experimental field belongs to the General soil type, Deep Red Brown Terrace Soils under Tejgaon soil series. The experiment consisted of two factors. Factor A: Calcium levels: 4 levels, Ca_1= 0 kg Ca ha^{-1} (0 kg gypsum ha^{-1}), Ca_2= 50 kg Ca ha^{-1} (250 kg gypsum ha^{-1}), Ca_3= 60 kg Ca ha^{-1} (300 kg gypsum ha^{-1}) and Ca_4= 70 kg Ca ha^{-1} (350 kg gypsum ha^{-1}); Factor B: Boron levels: B_1= 0 kg B ha^{-1} (0 kg Boric acid ha^{-1}), B_2= 1.275 kg B ha^{-1} (7.5 kg boric acid ha^{-1}), B_3= 1.7 kg B ha^{-1} (10 kg boric acid ha^{-1}), B_4= 2.125 kg B ha^{-1} (12.5 kg boric acid ha^{-1}). The experiment was laid in a split-plot design with three replications. Each experimental unit was divided into three blocks each of which representing a replication. There were total 16 treatment combinations. The total numbers of unit plots were 48. The size of unit plot was 3.8 m × 1.8 m. Spacing was maintained 30 cm x 15 cm. Distances between plot to plot and replication to replication were 1m and 1.5 m, respectively. For control plot half of urea along with other fertilizers as per treatment were applied during final land preparation as basal dose and thoroughly mixed with soil or other plots half urea and all other fertilizers as per treatment were applied by broadcasting 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 as per treatment. BARI Chinabadam-10 seeds were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

The data on growth parameters *viz*., plant lengtht (cm), number leaves $plant^{-1}$; yield parameters *viz.*, number of branches $plant^{-1}$, number of pods $plant^{-1}$, pod length (cm), 100-seed weight (g), seed yield (t ha^{-1}), stover yield (t ha^{-1}), biological yield (t ha^{-1}), harvest index (%); seed quality contributing characters *viz.*, germination percentage (%), protein content (%), oil content (%) and vitamin E content (mg/100g seed) were recorded.

The highest plant length 44.31 cm, 44.04 cm, 47.62 cm recorded at harvest from Ca_3 (60 kg Ca ha^{-1}), B_3 (1.7 kg B ha^{-1}) and Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment, respectively. Number of leaves $plant^{-1}$ increased up to 100 DAS and then decreased up to harvest with all the treatments. This might be due to plant focus on reproductive growth instead of vegetative growth. The highest number of leaves $plant^{-1}$ 42.36, 41.98 and 43.67 was recorded in Ca_3 (60 kg Ca ha^{-1}), B_3 (1.7 kg B ha^{-1}) and Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment at 100 DAS, respectively. Experiment data revealed that 60 kg Ca ha^{-1} + 1.7 kg B ha^{-1} produced the highest number of branches $plant^{-1}$ (8.50) and the lowest number of branches $plant^{-1}$ (5.33) produced from Ca_1B_1 (control) treatment. Highest number of pods $plant^{-1}$ 22.12, 21.94 and 23.53 recorded from Ca_3 (60 kg Ca ha^{-1}), B_3 (1.7 kg B ha^{-1}) and Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment, respectively and lowest number of pods $plant^{-1}$ from all control treatments. The maximum 100-seed weight (46.91 g), seed yield (2.35 t ha^{-1}), stover yield (3.37 t ha^{-1}), biological yield (5.72 t ha^{-1}) and harvest index (41.08 %) recorded from Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment and the minimum 100-seed weight, seed yield, stover yield, biological yield, harvest index recorded from Ca_1B_1 (control) treatment.

The results exhibited that the highest germination 90.50 % recorded with Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) and the minimum germination 78.80 % obtained with Ca_1B_1 (control), the maximum 38.72 % protein content obtained from Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment and the minimum 29.50 % protein content obtained from Ca_1B_1 (control) treatment. This may be due to strong synergistic effect among calcium and boron, which helps plant growth and development properly and ultimately increase protein content in groundnut kernel. The highest oil content 47.90 % recorded from Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) and lowest 32.25 % from Ca_1B_1 (control) treatment combinations. Because of their efficient use of large amounts of nutrients through their well-developed root systems and nodules, the boron and calcium compounds may have contributed to the increase oil content in groundnut seed. The maximum vitamin E content 9.68 mg/100g seed recorded with the application of Ca_3B_3 (60 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) which showed statistically similar results with Ca_3B_4 (60 kg Ca ha^{-1} + 2.125 kg B ha^{-1}) and Ca_4B_3 (70 kg Ca ha^{-1} + 1.7 kg B ha^{-1}) treatment. The minimum vitamin E content 4.95 mg/100g seed recorded with Ca_1B_1 (control) treatment. The possible reason behind the finding might be that calcium and boron helped to uptake the highest value of N, P, K, Fe and Mn and availability of all important nutrients on soil improved the nutritional status of kernel of groundnut.

Therefore, it can be concluded that calcium and boron management is important in groundnut cultivation as it was required in optimum amount during all growth stages of groundnut for its growth, yield and seed quality.

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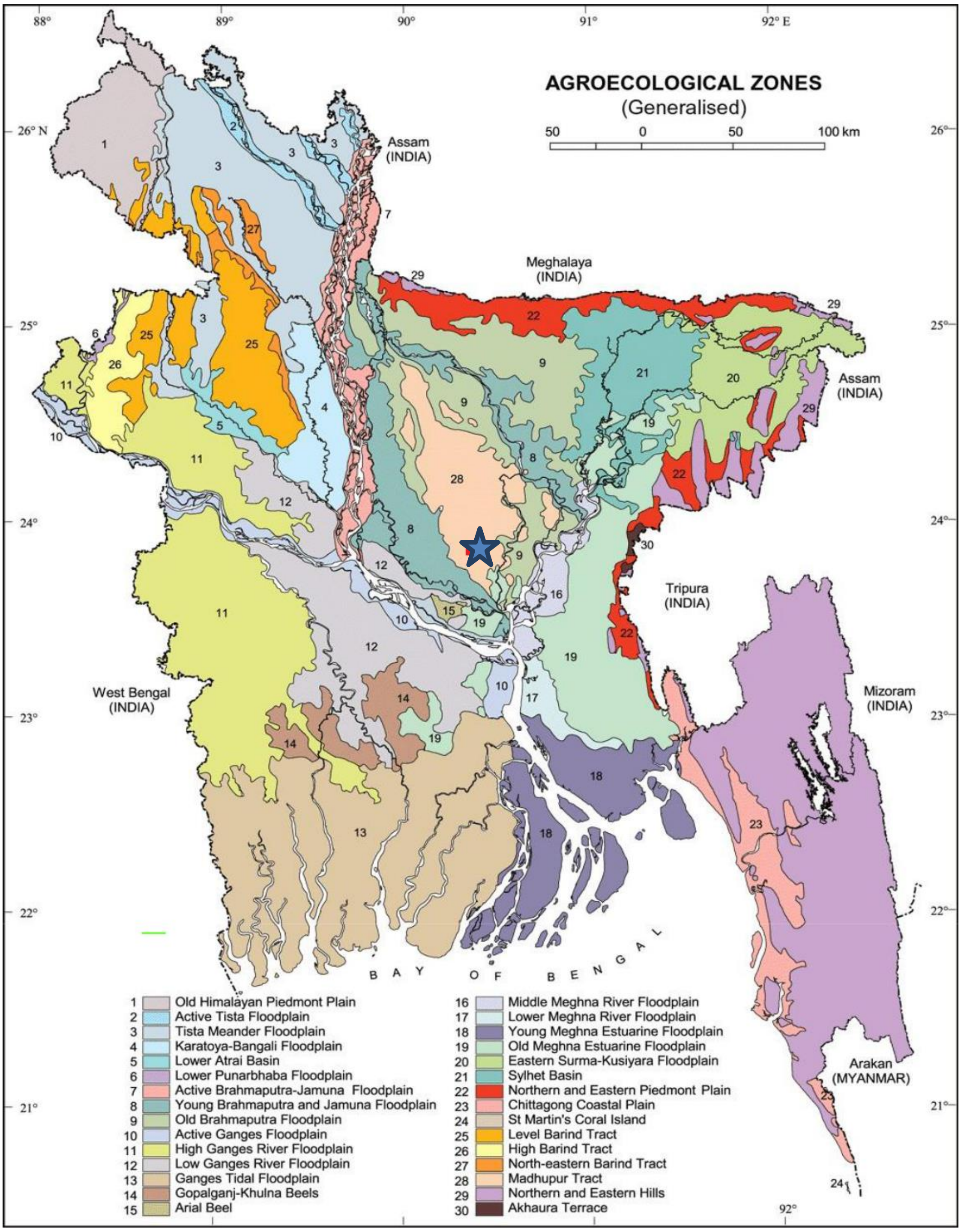
APPENDICES

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

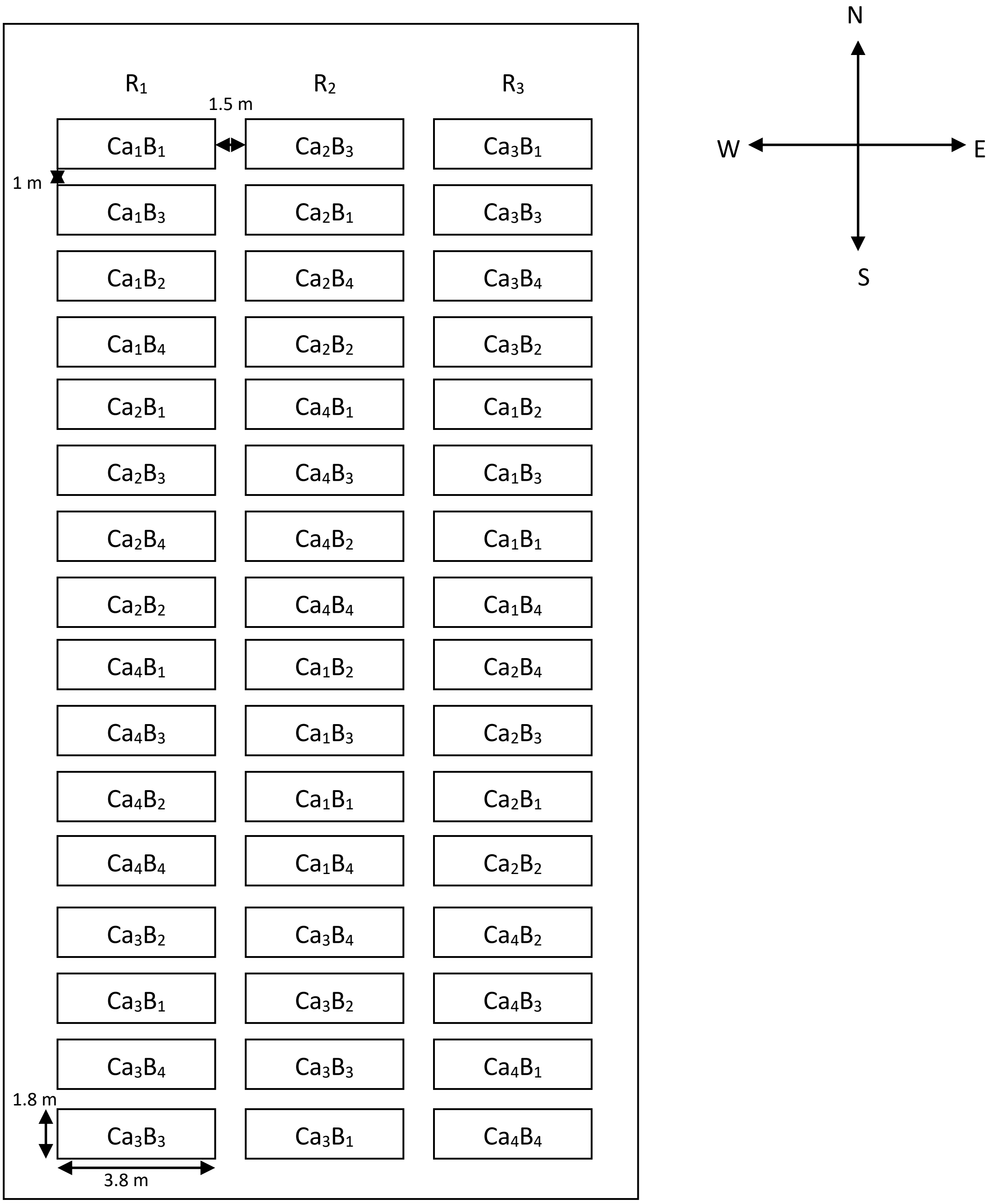
Source: Soil Resource Development Institute (SRDI)

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. Layout of the experiment



Total treatment combinations= 16

Total number of unit plots= 48

Size of unit plot= 3.8 m × 1.8 m

Distance between plot to plot= 1m

Distance between replication to replication= 1.5 m

Appendix IV. 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-1212

Appendix V. Mean square values of plant height at different days after sowing of groundnut in response to Ca, B and their interaction.

Sources of variation	Degrees of freedom	Mean square values of plant height at				
		25 DAS	50 DAS	75 DAS	100 DAS	Harvest
Replication	2	2.9737	9.0395	31.6850	72.5810	53.1080
Factor A	3	12.0083**	47.7196**	111.820**	199.597**	192.959**
Error	6	0.0479	0.0724	0.3570	1.5530	0.6160
Factor B	3	8.3658**	18.6833**	76.0560**	100.916**	101.383**
A × B	9	0.6700**	0.6414*	4.0670**	2.780*	3.1210*
Error	24	0.1762	0.2975	0.5330	1.100	1.031

* significant at 5% level of significance

** significant at 1% level of significanc

Appendix VI. Mean square values of number of leaves plant^{-1} at different days after sowing of groundnut in response to Ca, B and their interaction.

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	6.1877	50.7660	60.0620	90.250	90.250
Factor A	3	27.3663**	155.765**	276.642**	293.242**	278.678**
Error	6	0.0593	0.3490	1.2290	1.4170	0.9170
Factor B	3	14.6539**	49.7750**	190.325**	167.943**	119.246**
A × B	9	0.2762*	0.7020*	10.3420**	11.2580**	9.0900**
Error	24	0.1210	0.6200	0.9380	0.9580	1.0830

* 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 in response to Ca, B and their interaction.

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	0.6745	0.9120	1.3514	1.3225	2.0736
Factor A	3	2.9064**	5.6921**	4.9394**	6.1411**	7.7658**
Error	6	0.0052	0.0084	0.0270	0.0427	0.0825
Factor B	3	1.8562**	2.8847**	2.1676**	3.2132**	4.9245**
A × B	9	0.0821**	0.1013**	0.0735*	0.1184*	0.0969*
Error	24	0.0052	0.0249	0.0301	0.0510	0.0359

* 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 and weight of 100 seeds of groundnut in response to Ca, B and their interaction.

Sources of variation	Degrees of freedom	Mean square values of		
		Number of pods plant^{-1}	Length of pod	Weight of 100-seed
Replication	2	20.0256	0.0240	54.3910
Factor A	3	35.5327**	0.1814**	124.366**
Error	6	0.5123	0.0012	0.2240
Factor B	3	16.2668**	0.0829**	61.9780**
A × B	9	0.4228*	0.0038**	2.8580**
Error	24	0.3090	0.0011	0.7660

* significant at 5% level of significance

** significant at 1% level of significance

Appendix IX. Mean square values of pod yield, stover yield, biological yield and harvest index of groundnut in response to Ca, B and their interaction.

Sources of variation	Degrees of freedom	Mean square values of			
		Pod yield	Stover yield	Biological yield	Harvest index
Replication	2	0.0612	0.1156	0.8326	6.6049
Factor A	3	0.6748**	0.4111**	2.1386**	31.4398**
Error	6	0.0018	0.0043	0.0139	0.7436
Factor B	3	0.4021**	0.3003**	1.3968**	12.2209**
A × B	9	0.0205**	0.0168**	0.0736**	0.3394*
Error	24	0.0050	0.0047	0.0113	0.8909

* significant at 5% level of significance

** significant at 1% level of significance

Appendix X. Mean square values of germination percentage, protein content, oil content and vitamin E content of groundnut in response to Ca, B and their interaction.

Sources of variation	Degrees of freedom	Mean square values of			
		Germination	Protein content	Oil content	Vitamin E content
Replication	2	210.250	51.8400	95.0680	2.3562
Factor A	3	123.8950**	94.6962**	234.5040**	21.4056**
Error	6	2.4170	1.4733	1.8590	0.2101
Factor B	3	65.0900**	31.0606**	123.646**	10.9221**
A × B	9	3.9360*	1.5466*	7.1230*	0.4466*
Error	24	1.5420	0.5983	2.3280	0.1834

* significant at 5% level of significance

** significant at 1% level of significance

Plate 1. Experimental field located in Sher-e-Bangla Agricultural University, Dhaka-1207.

Plate 2: Seed sowing in the experimental plot.

Plate 3: Established seedling in the experimental plot.

Plate 4: Weeding in the experimental plots

Plate 5: Collecting data from the experimental plots.

Plate 6: Harvested groundnut plant from experiment plots.