EFFECT OF ZINC AND BORON FERTILIZER ON YIELD AND SEED QUALITY OF GROUNDNUT

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CERTIFICATE

This is to certify that the thesis entitled ***"EFFECT OF ZINC AND BORON FERTILIZER 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 (MS)*** *in* ***SEED TECHNOLOGY***, *embodies the result of a piece of bona fide research work carried out by* ***SHABRINA SHIRIN***, *Registration Number:* ***15-06732,*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

Dated:
Place: Dhaka, Bangladesh

Prof. Dr. Tuhin Suvra Roy
Supervisor
Department of Agronomy

Dedicated to My Beloved Parents

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The Author

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ABSTRACT

The experiment was carried out at the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during April 2021 to August 2021 to study the effect of zinc and boron fertilizer on yield and seed quality of groundnut. The experiment consisted of two factors; Factor A: Zinc fertilizer (4 levels) *viz.*, Zn_1: 0 kg zinc sulphate ha^{-1} (control), Zn_2: 2.50 kg zinc sulphate ha^{-1}, Zn_3: 5.00 kg zinc sulphate ha^{-1} and Zn_4: 7.50 kg zinc sulphate ha^{-1}, and factor B: Foliar application of boron (4 levels) *viz.*, B_1: Control (no boric acid L^{-1} of water), B_2: 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3: 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4: 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1}). The experiment was laid out in a Split-plot design with three replications. Plant length, no. of leaves $plant^{-1}$, no. of branches $plant^{-1}$, no. of pods $plant^{-1}$, length of pod, 100 seeds weight, pod yield $plot^{-1}$, pod yield, seed yield, stover yield, biological yield, harvest index, protein content, oil content, vitamin E content and germination percentage were compared among the individual and combinations effect of treatments. Results indicated that, zinc and foliar application of boron had significant influence on most of the growth, yield and yield contributing characters and seed quality of groundnut. In case of combined effect of zinc and foliar application of boron, the maximum pod yield (2.34 t ha^{-1}), seed yield (1.78 t ha^{-1}), protein content (38.60%), oil content (47.85%), vitamin E content (9.65 mg 100 g $seed^{-1}$) and germination (91.60%) were recorded from Zn_4B_4 treatment combinations. On the other hand, the minimum pod yield (1.43 t ha^{-1}), seed yield (0.90 t ha^{-1}), protein content (29.35%), oil content (32.64%), vitamin E content (4.75 mg 100 g $seed^{-1}$) and germination (73.90%) were recorded from Zn_1B_1 treatment combinations. Therefore, it can be concluded from the study that the treatment combinations of Zn_4B_4 (groundnut growing on 7.50 kg zinc sulphate ha^{-1} with foliar application of boron as boric acid @1.25 g L^{-1} of water) was found to be most suitable combination for the potential pod yield and seed quality of groundnut.

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LIST OF ACRONYMS

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

CHAPTER I

INTRODUCTION

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INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important food and oil crop. It is also known as the king of vegetable oilseed crops or the poor man's nut. It is a member of the Fabaceae family. The groundnut was thought to have originated in South America. Groundnut is one of the principal economic crops of the world that ranks 13th among the food crops (Mouri *et al*., 2018).

Groundnut is also known as earthnuts, peanuts, goobers, goober peas, pindas, jack nuts, pinders, manila nuts, g-nuts and monkey nuts; the last of these is often used to mean the entire pod (Annadurai and Palaniappan, 2009). In Bangladesh, it is popularly known as ‘‘cheenabadam’’. Aside from its nutritional value, groundnut is a major oilseed crop. According to BBS (2020), groundnut is grown on 30791 hectares with a production of 55108 tons during Rabi and Kharif seasons in Bangladesh.

The importance of groundnut in the global economy is rapidly increasing due to its demand as oil for making margarine, cooking oil, soaps, and a variety of other household products (Vessey and Buss, 2002). It is very useful in crop rotation because of its ability to fix atmospheric nitrogen into the soil, thus enriching soil fertility for the benefit of subsequent crops on the same farm land (Oranekwulu, 1995). Globally, 50% of groundnut production is used for oil extraction, 37% for confectionary use, and 12% for seed production (Shendage *et al*., 2018). Seed contains approximately 38-50% oil, 26% protein, 11.5% carbohydrate, 2.3% ash, 2.5% minerals, and 6% water (Oyewole *et al.*, 2020). It also contains a lot of calcium, potassium, phosphorus, magnesium, and vitamins B and E (Mouri *et al.*, 2018).

Micronutrients (*i.e.*, boron, chlorine, copper, iron, manganese, molybdenum and zinc) are essential for healthy growth and reproduction of plants. Micronutrients deficiency are widely observed in humans, animal and plants, especially in many arid countries, due to high pH, low organic matter, salt stress, continual drought and imponderable application of fertilizers (Malakouti, 2008). Malnutrition accounts for more than 30 million deaths a year in mostly resource-poor families in the developing world. Much of this malnutrition is the result of insufficient intake of available trace elements in the diets of the poor peoples. Through linking agricultural systems, human nutrition could have of sustainable solutions against malnutrition in future by changing agricultural systems in the ways that will help supply enough essential trace elements to the poor to meet their needs for leading healthy and productive lives (Welch, 2008). Micronutrients are essential elements for plant growth and needed in small quantities. Higher yield and quality characters of agricultural products increase with micronutrients application (Tavakoli *et al.,* 2014). Whenever the supply of one or more of these elements is insufficient, yields will be reduced and the quality of crop products impaired, but crop species and cultivars vary considerably in their susceptibility to deficiencies (Alloway, 2008).

Globally, zinc (Zn) is now recognized as the 5^{th} major nutrient deficiency in human beings mainly due to its deficiency in the soil. It has specific and essential physiological functions in plant metabolism, influencing yield and quality (Suri *et al.*, 2008). It is very important crop nutrient that plays a vital role in growth and development of crops by enhancing the synthesis of growth hormone and chlorophyll (Chattha *et al*., 2017). It is involved in the synthesis of growth promoting hormones and the reproductive process of many plants (Hassan *et al.*, 2019). It plays an important role as a metal component of enzymes (alcohol dehydrogenase, superoxide dismutase, carbonic anhydrase and RNA polymerase) or as a functional, structural or regulator cofactor of a large number of enzymes (Suganya *et al.*, 2020). It is required in various metabolic processes as catalysts. It also increases the content of protein, calorific value, amino acid and fat in oilseed crop. It catalyses the process of oxidation in plant cells and is vital for transformation of carbohydrates, regulates the consumption of sugar, increases source of energy for the production of chlorophyll, aids in the formation of auxin and promotes absorption of water (Radhika and Meena, 2021).

Zinc deficiency in crop plants is a widespread nutritional disorder in a variety of soils. It is assumed that application of micronutrient may increase the productivity of groundnut due to its multifarious role in plant metabolism (El-Habbasha *et al.*, 2013). Thus, proper plant nutrition is an important factor for improving yield and quality of crop. As balanced fertilization support the demands of plant by regulating the metabolic processes in yield formation towards attaining the crop quality.

Boron (B) is considered to be an another essential micronutrient element for plant growth and development. It is a micronutrient required by plants in a very small quantity which rapidly becoming deficient in soils (Tahir *et al.*, 2009). It is an essential element needed for normal growth and development of peanut plant (Gascho and Davis, 1995). It regulates carbohydrate metabolism and plays role in seed formation (BARC, 2012). Application of B in soil significantly increases the growth and yield of groundnut (Kabir *et al.*, 2013; Singaravel *et al.*, 2016). It has the ability to increase photosynthetic and enzymatic activity in plant; moreover, it causes pollen grain germination, pollen tube growth and viability of pollen grains (Cakmak, 2008). B makes the stigma receptive and sticky, makes pollen grain fertile, and enhances the pollination (Kaisher *et al.*, 2010). It was evident that application of B enhanced the seed and oil yield and protein percentage in groundnut (Darwish *et al.*, 2002; Datta *et al.*, 1998). But B deficiency problems for crop production have been identified (Ahmed and Hossain, 1997) because application of B in crops is limited at farmers' field (Nasreen *et al.*, 2015). B deficiency leads to several physiological damages in plant. It is considered to be essential for sugar transport, synthesis of cell wall, cell wall structure, metabolism of carbohydrate, RNA, phenol and indole acetic acid, respiration and membrane integrity. Additionally, foliar spray enables plants to absorb the applied nutrients from the solution through their leaf surface and thus, may result in the economic use of fertilizer (Helmy and Shaban, 2008). Thus, the proper micronutrient fertilizer management of groundnut crop with reference to amount and method of application may have significant effect on yield and quality (Veeramani and Subramaniyan, 2011).

Therefore, this study was aimed at examining the effect of zinc and foliar application of boron on growth, yield and seed quality of groundnut. Under the above circumstances, the present experiment was undertaken with the following objectives:

- To examine the effect of zinc and/or boron on growth, yield and seed quality of groundnut, and
- To sort out the suitable combination of zinc and boron for having better yield and quality groundnut seed.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

An attempt was made in this section to collect and study relevant information available in the country and abroad regarding the effect of zinc and boron fertilizer on growth, yield and seed quality of groundnut to gather knowledge helpful in conducting the present research work.

2.1 Effects of zinc on growth, yield and seed quality of groundnut

Al-Yasari and Al-Yasari (2022) conducted a field experiment on a local peanut (*Arachis hypogaea* L.) cultivar transplanted in the spring season of 2021 at the Al-Hussainiya region, Holy Kerbala, Iraq to determine peanut response to weed control, foliar application of nano-zinc, and their interaction in growth, yield and quality traits. The experiment laid out in a split-plot design with two factors (weed control and nano-zinc foliar application) had three replications. The nano-zinc concentrations (0, 50, and 100 mg L^{-1}) occupied the main plots, with the weed control treatments were kept in sub-plots. Weed control included the control (T_0- no weed control), manual hoeing (T_1), and weed control with pre-emergence (pre-em) herbicides, i.e., Trifluralin (T_2) and Pendimethalin (T_3), and post-emergence (post-em) herbicides, *viz.*, Oxyfluorfen (T_4) and Clethodim (T_5). The results showed that post-em herbicide Oxyfluorfen gave superior enhancement on the vegetative dry weight, pods $plant^{-1}$, seeds $plant^{-1}$, total pod yield, protein, and zinc in the seeds with increased values of 52.0%, 265.1%, 254.5%, 211.9%, 13.2%, and 25.5%, respectively, compared with the control treatment. Nano-zinc (100 mg L^{-1}) foliar application led to a significant increase in the above traits with increased rates of 2.5%, 21.2%, 40.6%, 7.4%, 8.2%, and 89.2%, respectively, compared with the control. The interaction between both factors showed significant superiority compared with no weeding and separate application of weed control combined with chemical herbicides and nano-zinc application. The interaction between the post-em weed management (Oxyfluorfen) and nano-zinc (100 mg L^{-1}) application showed highly superior results compared with other treatments in the studied traits.

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

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

Nakum *et al.* (2019) conducted a field experiment on the effect of zinc and iron fertilization on yield of groundnut (*Arachis hypogaea* L.) under dryland condition at Main Dry Farming Research Station, Junagadh Agricultural University, Targhadia during Kharif season. The experiment composed of ten treatments *viz*., T_1 (control), T_2 (RDF), T_3 (RDF + 10 kg $ZnSO_4$ ha^{-1}), T_4 (RDF + 15 kg $FeSO_4$ ha^{-1}), T_5 (RDF + 10 kg $ZnSO_4$ ha^{-1} + 15 kg $FeSO_4$ ha^{-1}), T_6 (RDF + spray of 1% $ZnSO_4$ at 30 and 45 DAS), T_7 (RDF + spray of 1 % $FeSO_4$ at 30 and 45 DAS), T_8 (RDF + spray of 1% $ZnSO_4$ + 1% $FeSO_4$ at 30 and 45 DAS), T_9 (RDF + 5 kg $ZnSO_4$ ha^{-1} + 1% $ZnSO_4$ spray at 30 and 45 DAS) and T_{10} (RDF + 7.5 kg $FeSO_4$ ha^{-1} + 1% $FeSO_4$ spray at 30 and 45 DAS). These treatments were laid out in RBD with four replications. The experiment was conducted on a clayey soil which was slightly alkaline in reaction with pH 8.11 and no saline (EC 0.32 dS m^{-1}), medium in available nitrogen (276 kg ha^{-1}), low in phosphorus (22.40 kg ha^{-1}), high in potassium (463 kg ha^{-1}), medium in sulphur (12.2 mg kg^{-1}), high in iron (10.08 mg kg^{-1}), medium zinc (0.58 mg kg^{-1}). Groundnut variety 'GG-20' was sown in the first week of July at a spacing of 60 cm × 10 cm using seed rate of 120 kg ha^{-1} and fertilizer application was as per treatment. Significantly the highest pod (2527 kg ha^{-1}) and haulm (5342 kg ha^{-1}) yields of groundnut were recorded under combined application of RDF + spray of 1% $ZnSO_4$ + 1% $FeSO_4$ at 30 and 45 DAS, but it remained at par with individual application of zinc and iron as basal in soil alone or in combination as soil plus foliar application. Conversely, significantly the lowest pod and haulm yields were noted under control. Economical evaluation showed that the maximum gross realizations (122516 ha^{-1}), net realization of (94957 ha^{-1}) with B:C ratio of (4.45) were obtained from the treatment spray of 1% $ZnSO_4$ + 1% $FeSO_4$ at 30 and 45 DAS besides the recommended dose of nitrogen and phosphorus and lowest remained over control. Based on the results of experimentation, it was concluded that the combined foliar application of 1% $ZnSO_4$ + 1% $FeSO_4$ at 30 and 45 DAS along with recommended dose of nitrogen and phosphorus (12.5:25 kg ha^{-1}) in the Kharif groundnut gave the maximum production and higher net realization, apart from improving soil fertility under dryland condition.

Sabra *et al.* (2019) carried out two field experiments during two successive summer seasons (2015 and 2016) at the Production and Research Station, National Research Centre, El- Nubaria Province, El-Beheira Governorate, Egypt to investigate the response of two groundnut (Giza 6 and Gregory) varieties to some micronutrients foliar application i.e., Zinc, Manganese and Boron and their interaction with different growth stages on yield, yield attributes and some chemical traits of groundnut seeds under reclaimed sandy soil condition. Cultivar Giza 6 showed high value of growth characters compared with Gregory variety for all traits except plant height at 75 DAS. On the other hand, data illustrated that combination of Zn + Mn + B surpassed overall treatments and control. The interaction effect between groundnut varieties and micronutrient foliar application revealed a high significant difference for all studied traits. Yield attributes (number of pods plant^{-1}, number of seed plant^{-1}, weight of pods plant^{-1} and seed weight plant^{-1} and 100-seed weight) were affected significantly due to foliar spraying with micronutrient treatments. The data revealed that Giza 6 showed high performance for all studied traits comparing with Gregory. Mixture of Zn + Mn + B recorded high value comparing with dual effect of Zn + Mn, Zn + B and Mn + B also single effect Zn, Mn and B for yield components. Influence of interaction revealed that Giza 6 variety recorded high performance for all yield characters except harvest index and oil %. Therefore, Giza 6 variety responded positively to treatments with Zn 400 ppm + Mn 400 ppm + B 0.06 as boric acid for pod, seed, straw, biological, oil and protein yield fed^{-1}.

Maharnor *et al.* (2018) carried out a field experiment to study effect of zinc on yield and quality of groundnut (*Arachis hypogaea* L.) in inceptisol during the *Kharif* season in the year 2015-2016 at departmental farm of Soil Science and Agricultural Chemistry, college of Agriculture Latur. The experiment was laid out in factorial randomized block design with 16 treatment combinations (four levels of zinc *viz*., Zn_0, Zn_1, Zn_2 and Zn_3 and four cultivars *viz.*, LGN-1, LGN-123, JL-24, JL-776) along with three replications. The effect of Zn on kernel and haulm yield as well as quality parameters such as oil and protein of groundnut were significantly increased with application of $ZnSO_4$ @ 30 kg ha^{-1} + RDF, followed by $ZnSO_4$ @ 15 kg ha^{-1} + RDF. However, increment of zinc (45 kg ha^{-1}) did not prove superior over other treatments. The magnitude of response of groundnut cultivars to zinc levels was in the order of JL-24 > LGN-1 > JL-776 > LGN-123 in terms of yield and quality of groundnut. Thus, it can be concluded that application of Zn along with recommended dose of NPK to different cultivars was found to be beneficial in increasing the yield and quality of groundnut over control on low zinc containing Inceptisol soil.

Irmak *et al.* (2015) carried out an experiment to evaluate the effect of soil and foliar Zn fertilization on two varieties of peanut's (*Arachis hypogaea*) yield and few yield components. Soil applications of Zn doses were 0, 10, 20 and 40 kg ha^{-1} whereas 0, 0.5, 1 and 1.5 kg ha^{-1} Zn were sprayed to leaves. An application of variable rates of Zn led to remarkable increase in yield and 100-seed weight. The effect of Zn treatment found to be statistically important at $P<0.01$ levels. The highest yield was obtained at COM variety as 6580.0 kg ha^{-1} with 0.5 kg ha^{-1} Zn foliar application. The lowest yield was measured at NC-7 variety's control plot with 3660.0 kg ha^{-1} in 2007. Foliar application Zn was statistically determined to be important to NC-7 variety peanut's grain Zn concentration at $P<0.05$ levels in each year. The economic analyses revealed that 0.5 kg ha^{-1} foliar application of Zn provided a maximum profit with 10271.2 USD Dollars ha^{-1}.

Rahevar *et al.* (2015) conducted a field experiment during the summer season of 2012 in loamy sand soil of agronomical farm, C.P.C.A., S.D.A.U., S.K. Nagar to study the effect of soil application of FYM with combination of Fe and Zn with recommended dose of N (25 kg ha^{-1}) and P (50 kg ha^{-1}) on growth, yield and quality by groundnut crop under North Gujarat Agro-climatic condition. Application of FYM @ 5 t ha^{-1} with 5 kg Fe ha^{-1} + 4 kg Zn ha^{-1} to groundnut considerably increased yield, yield attributes and quality parameters. The maximum cost benefit ratio was obtained in groundnut crop with application of FYM @ 5 t ha^{-1} with 5 kg Fe ha^{-1} + 4 kg Zn ha^{-1}.

Saha *et al.* (2015) carried out a field experiment to evaluate the effect of zinc (Zn), boron (B) and sulphur (S) on the yield and quality of groundnut with three levels of Zn (0, 5, 10 kg Zn ha^{-1} as Zn-EDTA as basal), two levels of B (0 and 0.25% boric acid as foliar spray) and three levels of S (0, 25, 50 kg S ha^{-1} as $CaSO_4.2H_2O$) in a factorial RBD. Basal application of Zn @ 5 and 10 kg ha^{-1} caused an increase in nut yield by 3.7% and 28.3% respectively over control, whereas, application of S @ 25 and 50 kg ha^{-1} increased the nut yield by 38.3% and 56.6% respectively over control. Conjoint application of Zn @ 10 kg ha^{-1} and S @ 50 kg ha^{-1} caused an increase in nut yield up to 73.4% over the control. Results, therefore, revealed that conjoint effect of S and Zn towards nut yield was more effective than that of B application. Application of Zn, S and B significantly increased their nutrient uptake in nuts. On an average, S, Zn and B uptake by groundnut ranged from 11.4 to 21.0 kg ha^{-1}, 0.14 to 0.40 kg ha^{-1} and 0.12 to 0.25 kg ha^{-1}, respectively. Integrated mode of application of Zn, B and S showed a positive interaction as yield increase with their uptake in groundnut. Oil content in nuts ranged from 45.3 to 54.4%, while iodine value ranged from 97.8 to 90.5%. Application of S and Zn significantly increased the oil content, while it significantly decreased the iodine value in groundnut. So, application of micronutrients *viz*. Zn and B as well as S fertilization could be a useful strategy not only to increase the yield but also the quality of groundnut.

El-Habbasha *et al.* (2013) carried out an experiment to study the effect of nitrogen fertilizer and Zn foliar application at different growth stages on yield, yield attributes and some chemical traits of groundnut. Results showed that increasing the use of Zn foliar application either at flowering or seed filling stages significantly increased number of pods plant^{-1}, weight of pods plant^{-1}, number of seed plant^{-1}, weight of seeds plant^{-1}, 100-pod weight, 100-seed weight, pod, seed and straw yield fed^{-1}, oil yield, seed protein content, N and K content in the seed and straw compared to control treatment. The studied characters of yield and yield attributes were significantly affected by the interaction between nitrogen fertilizer levels and foliar Zn application. Groundnut treatment with 40 kg N fed^{-1} + Zn foliar application at seed filling stage recorded the highest significant values of most studied characters than the other treatments followed by the same nitrogen level and Zn foliar application at flowering stage. The data of nitrogen use efficiency calculated (kg seeds kg^{-1} N) revealed that there were synergistic effect of the combined application of nitrogen and zinc either at flowering or seed filling stages.

Sharma *et al.* (2013) reported that Girnar 2 variety of groundnut was found superior with respect to the plant height, dry matter accumulation, number of branches and number of nodules. Maximum plant height was recorded in variety TG37A. The yield attributes (number of pods per plant, number of kernels per pod, seed index, shelling percentage) and pod, haulm and biological yields were significantly higher in variety Girnar 2, but were almost same as those of RG510. Furthermore, plant height, dry matter accumulation, number of branches plant^{-1}, pods plant^{-1}, no. of kernels pod^{-1}, pod yield, haulm yield, biological yield, harvest index, number of nodules, shelling percentage and seed index etc. significantly increased with the application of Zn upto 5 kg ha^{-1}.

Aboelill *et al*. (2012) stated that the growth parameters (plant height, number of branches plant^{-1}, number of leaves plant^{-1}, stem, root, leaves, and whole plant) were significantly influenced by different treatments of foliar spraying at 75 DAS for Giza 6 varieties of groundnut.

Tathe *et al.* (2008) conducted a pot culture experiment in Vertisols to study the effects of levels of sulphur and zinc, separately and their combination on yield, oil, protein content and uptake of sulphur and zinc by kharif groundnut (cv. Phule Pragati). Application of 120 kg S ha^{-1} recorded significantly the highest dry pod yield, oil and protein content as well as sulphur uptake by groundnut and it was at par with 80 kg S ha^{-1} application. While 80 kg S ha^{-1} application showed highest zinc uptake. As regards zinc application, 40 kg Zn ha^{-1} recorded significantly the highest pod yield, protein content and zinc uptake by groundnut whereas application of 20 kg Zn ha^{-1} recorded the highest oil content and sulphur uptake by groundnut. Interaction effects were found to be non-significant.

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

2.2 Effect of boron on growth, yield and seed quality of groundnut

Ghazimahallah *et al.* (2022) conducted an experiment to evaluate the effect of biochar, mycorrhiza, and foliar application of boron on growth and yield of peanuts. The experiment was based on a completely randomized block design with three replications. The experimental treatments included nano boron fertilizer at two levels (N_0: without nano boron fertilizer and N_1: foliar fertilization with nano boron fertilizer), biochar at three levels (B_0: without biochar, B_1: peanut shell biochar, and B_2: Azolla biochar), and mycorrhizal fungi at two levels (M_0: without mycorrhizal inoculation and M_1: mycorrhizal inoculation). The experimental results showed that the interaction effect of foliar fertilization with nano boron, biochar application, and inoculation with mycorrhizal fungi on the studied quantitative traits (e.g., green pod yield, grain pod yield, grain yield, number of seeds per plant, number of pods per plant, and weight of 100 seeds) and qualitative traits (e.g., grain nitrogen, phosphorus content, and percentage of grain protein) was significant. According to the results, the highest yield of green pods (23,180 kg ha^{-1}), grain pods yield (13,230 kg ha^{-1}), grain yield (8953 kg ha^{-1}), and no. of seeds $plant^{-1}$ (160.3) were obtained in foliar fertilization with nano boron without biochar and mycorrhizal inoculation. In addition, foliar fertilization with nano boron, application of Azolla biochar, and no inoculation with mycorrhiza had the highest content of nitrogen (3.98%) and grain protein (33.87%). Thus, according to the results of this experiment, proper and balanced nutritional management of peanuts leads to better yields. Foliar fertilization with nano boron can help to increase the quantitative and qualitative yield of peanuts. Biochar application and inoculation with mycorrhizal fungi conserve the available resources, improve the soil's physical and chemical properties, and increase the quantity and quality of peanut seeds.

Nandi *et al.* (2020) conducted a pot experiment to investigate the effect of combination between foliar zinc and boron on groundnut growth, yield, nutrient uptake and its accumulation in pods. The pot experiment was comprised three levels of Zn (0, 0.5 and 0.75% Zn), three levels of B (0, 0.3 and 0.45% B) and their combinations. The treatments were replicated thrice. Zn and B were applied through foliar spray twice at vegetative and flower initiation stages. Chlorophyll content, leaf area, root-shoot dry biomass, plant height, nutrient uptake and nutrient concentrations in pods were studied. Foliar spray of Zn and B jointly increased the leaf area to the tune of 55% and 29% at the corresponding stages. Despite the sole application of B and Zn increased the leaf chlorophyll content in groundnut, the combined applications were much more prominent. Moreover, lower level of Zn combined with higher level of B significantly ($p<0.05$) had higher uptake of N (18.8%), P (11.5%) and K (5.9%) over higher level of sole Zn application. The improved biomass accumulation of groundnut amplified the efficient utilization of primary nutrients and resulted in higher nutrient uptake as well as their concentration in pods. Groundnut when sprayed with elevated doses of Zn and B produced the maximum yield (30.8 g plant^{-1}). Spraying of Zn and B increased plant biomass, leaf area, chlorophyll content noticeably and with the increase in concentration of Zn and B in spray, the increment became quite intense. The combined spray of Zn and B at critical growth stages promoted better growth and productivity of groundnut.

Hirpara *et al.* (2019) conducted a pot experiment was at Department of Agricultural Chemistry and Soil Science, College of Agriculture, Junagadh during summer season of 2016 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.

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

Poonguzhali *et al.* (2019) carried out a study in vylogam soil series 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 highest oil and crude protein content in the soil series with the values of 50.6% oil content 15.0% of crude protein content in the soils of Vylogam soil series.

Mehmood *et al*. (2018) reported that soil application of B @ 2 kg ha^{-1} recorded the highest oil content of 36.6% over control 32.2% and the achene protein was enhanced upto 20.38% over control (14.7%).

Poonguzhali and Pandian (2018) carried out a study 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). The soil and foliar application of B improved the growth accompanied by increased B concentration in plant parts.

Kumar *et al.* (2016) carried out an experiment was 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) conducted an experiment to study the response of boron and light on morph-physiology and pod yield of two peanut varieties. Treatments considered two peanut varieties, namely, Dhaka-1 and BARI Chinabadam-8, three levels of boron (B), namely, 0 kg B ha^{-1} (B_0), 1 kg B ha^{-1} (B_1), and 2 kg B ha^{-1} (B_2), and two levels of light, namely, normal day light (≈12 h light) and normal day light + 6 h extended red light at night (≈18 h light). Result revealed that days to first-last emergence and days to first-50% lowering took shorter times and vegetative growth, pods dry weight $plant^{-1}$, pod yield, and germination were markedly increased with the application of boron. Vegetative growth and germinations were significantly increased in light, but the lowest leaf area, pods dry weight $plant^{-1}$, and pod yield were found in light. Without germination, the highest vegetative growth, reproductive unit, and pod yield were observed from BARI Chinabadam-8. Days to first-last emergence, days to first-50% lowering, and number of branches plant^{-1} were found linearly related to pod yield.

Nadaf and Chidanandappa (2015) 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.

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

El-Kader and Mona (2013) carried out a field experiment during the summer seasons of 2011 and 2012 on peanut (*Arachis hypogaea* L.) cv. (Giza 6) grown in a sandy soil at a farm at El-Quassasin region, Ismailia Governorate, Egypt, to study the effect of sulfur (S) application at rate of 200 kg fed^{-1}, foliar spraying with Zn, B and their combinations on yield and its components as well as seed quality and some chemical contents of seeds. The experiment was designed in complete randomized blocks with three replicates. Results indicated that, application of sulfur (S) and foliar spraying with micronutrient (Zn and B) together had the significant effect on peanut seed yield and its attributes as well as seed quality. Their highest values were obtained when plants treated with sulfur (S) combined with foliar spraying with (Zn + B). Meanwhile, the highest amount of nutrient content was obtained with 200 kg S fed^{-1}.

Combined with foliar spraying with 3.33 g ($ZnSO_4$-$7H_2O$) L^{-1} $plot^{-1}$, (2.7 kg $ZnSO_4$ fed^{-1}) and 0.83 g ($Na_2B_4O_7$-$10H_2O$) L^{-1} $plot^{-1}$ (0.7 kg borax fed^{-1}), for Zn and B respectively. Application of different treatments had the significant effect on available N, P, K and S in soil. The highest values of available N, P, K and S were observed with the combined treatment of (S + Zn + B). The highest values of available Zn and B were obtained due to the application of sulfur (S).

Kaisher *et al*. (2010) reported that the application of boron increase in plant height of groundnut crop might be due to soil and foliar applied B, which could be attributed to metabolic regulation and enzymatic process including photosynthesis, respiration and symbiotic N-fixation.

Kushwaha *et al*. (2009) found that increasing levels of boron application significantly improved the protein content.

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. Soil application of 1.0 kg B ha^{-1} as agricol, solubor and borosol increased pod yield by 8-23, 6-18, 12-18%, respectively compared to 9-28% by borax and 5-24% by boric acid. Foliar application (0.1% aqueous solution) of borosol, chemiebor and solubor showed similar response in increasing the pod yield by 7-39, 6-32, and 6-35%, respectively.

Chitdeshwari and Poongothai (2003) reported that the soil application of Zn 5 kg ha^{-1} + B 1 kg ha^{-1} + S 40 kg ha^{-1} significantly increased the groundnut pod yield to the tune of 24.2% for TMV 7 and 14.8% for JL 24 over control.

Subrahmaniyan *et al.* (2000) reported that combined application of $ZnSO_4$@ 5 kg ha^{-1} + borax @ 5 kg ha^{-1} + $FeSO_4$ @ 10 kg ha^{-1} recorded the maximum yield attributes *viz*., number of matured pods $plant^{-1}$ (14.6), 100-kernel weight (47.61 g) and shelling percentage (70.60%) compared to other treatments under red sandy loam soil with low fertility status.

Kumar *et al*. (1996) conducted a field experiment in B deficient acid sedentary soils of Ranchi and they found that the groundnut responded significantly to boron application @ 3 kg ha^{-1} and pod yield increased remarkably from 1140 kg ha^{-1} in control to 1530 kg ha^{-1}. However, further increase in B application up to 4.5 kg ha^{-1} reduced pod yield.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter describes the materials and methods which were used in the field to conduct the experiment to study the effect of zinc and boron fertilizer on yield and seed quality of groundnut. The materials and methods used for conducting the experiment have been presented in this chapter. It comprises a short description of experimental site, soil and climate, variety, growing of the crops, experimental design and treatments and collection of data presented under the following headings:

3.1 Description of the experimental site

The research work was conducted at experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, during the period from April 2021 to August 2021. The location of the site was 23°74′ N Latitude and 90°35′ E Longitude with an elevation of 8.2 meters from the sea level (Anon, 1987) and presented in Appendix I.

3.2 Soil characteristics

The texture of the soil in the experimental field was silty loam. The soil in the experimental area is part of the Modhupur Tract (UNDP, 1988) and belongs to AEZ No. 28. Before conducting the experiment, a soil sample from the experimental plot was obtained from a depth of 0-30 cm and examined at the Soil Resource Development Institute (SRDI), Soil Testing Laboratory, Khamarbari, Dhaka which is shown in Appendix II.

3.3 Climate and weather

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

3.4 Crop/plating material

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

3.5 Treatments under the investigation

The experiment consisted of two factors *viz.* zinc levels and foliar application of boron as mentioned below:

Factor A: Zinc levels (4)

Zn_1= 0 kg zinc sulphate ha^{-1} (Control)
Zn_2= 2.50 kg zinc sulphate ha^{-1}
Zn_3= 5.00 kg zinc sulphate ha^{-1}
Zn_4= 7.50 kg zinc sulphate ha^{-1}

Factor B: Foliar application of boron (4 levels)

B_1= Control (no boric acid L^{-1} of water)
B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1})
B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1})
B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Treatment combinations- Sixteen treatment combinations: Zn_1B_1, Zn_1B_2, Zn_1B_3, Zn_1B_4, Zn_2B_1, Zn_2B_2, Zn_2B_3, Zn_2B_4, Zn_3B_1, Zn_3B_2, Zn_3B_3, Zn_3B_4, Zn_4B_1, Zn_4B_2, Zn_4B_3 and Zn_4B_4.

3.6 Experimental design and layout

The experiment was laid out in a Split-plot Design with three replications where zinc fertilizers were considered in the main plot and foliar application of boron in sub plot. Four levels of zinc fertilizer and four levels of foliar application of boron gave altogether 16 treatment combinations of the experiment. The area of the experimental plot was divided into three equal blocks. Each block was divided into 4 equal main plots and the main plots were further divided into 4 unit plots. The size of each unit plot was 2.00 m × 2.00 m = 4.00 m^2. Distances between replications and plots were 0.75 m and 0.50 m, respectively. The layout of the experimental field is presented in Appendix IV.

3.7 Seed collection

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

3.8 Description of the variety

Developed by	Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh
Year of release	2016
Main characteristics	Plant is erect type, plant length 40-45 cm, number of pods plant^{-1} 22-25, cluster pod bearing, surface of the pod not smooth and vain prominent, seeds brown in color and medium in size, 100-seed weight 45 g. Crop duration in Rabi season 140-155 days and kharif season 120-135 days. Oil content is 48-50% and this variety is tolerant to drought and diseases.
Planting season and time	This variety is cultivated throughout the country in rabi and kharif season, sowing time in rabi season Mid October to Mid-November and kharif season July to August.
Yield	In rabi season 2.2-2.5 t ha^{-1}; in kharif season 2.0-2.2 t ha^{-1}

3.9 Land preparation

The plot selected for the experiment was opened in the last week of March, 2021 with a power tiller, and was exposed to the sun for a few days, after, which the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubbles were removed and finally obtained a desirable tilth of soil for seed sowing. The land preparation was completed on 2nd April 2021. The individual plots were made by making ridges (20 cm high) around each plot to restrict lateral runoff of irrigation water.

3.10 Collection and preparation of initial soil sample

The initial soil samples were collected before land preparation from a 0-15 cm soil depth. The samples were collected by means of an auger from different location covering the whole experimental plot and mixed thoroughly to make a composite sample. After collection of soil samples, the plant roots, leaves etc. were picked up and removed. Then the samples were air-dried and sieved through a 10-mesh sieve and stored in a clean plastic container for physical and chemical analysis and subsequently analyzed from Soil Resources Development Institute (SRDI), Farmgate, Dhaka- 1215.

3.11 Fertilizers and manure application

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

Fertilizers	Doses ha^{-1}
Urea	25 kg
TSP	160 kg
MoP	85 kg
Gypsum	170 kg
$ZnSO_4$	As per treatment
Boric acid	As per treatment

Half of urea along with other fertilizers were applied during final land preparation as basal dose as per treatment and thoroughly mixed with soil. The rest half urea was applied at 45 DAS when flowers were initiated by side dressing. Foliar applications of boron were applied at 30 DAS and at 60 DAS (pod development stage).

3.12 Seed sowing

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

3.13 Intercultural operations

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

3.13.1 Irrigation and drainage

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

3.13.2 Gap filling, thinning, weeding and mulching

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

3.13.3 Earthing up

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

3.13.4 Plant protection

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

3.14 Harvesting and post-harvest operation

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

3.15 Data collection and recording

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

i. Plant length
ii. Number of leaves $plant^{-1}$
iii. Number of branches $plant^{-1}$
iv. Pod length
v. Number of pods $plant^{-1}$
vi. Pod yield $plot^{-1}$
vii. 100-seed weight
viii. Seed yield $plot^{-1}$
ix. Pod yield
x. Seed yield
xi. Stover yield
xii. Biological yield
xiii. Harvest index
xiv. Protein content
xv. Oil content
xvi. Vitamin E content
xvii. Germination percentage

3.16 Procedure of recording data

3.16.1 Plant length

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

3.16.2 Number of leaves plant^{-1}

Five plants were selected randomly from the inner rows of each plot. No. of leaves plant^{-1} was counted from each plant sample at 25, 50, 75, 100 DAS and at harvest and then the average value noted.

3.16.3 Number of branches plant^{-1}

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

3.16.4 Pod length

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

3.16.5 Number of pods plant^{-1}

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

3.16.6 Pod yield plot^{-1}

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

3.16.7 Weight of 100-seed

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

3.16.8 Seed yield plot^{-1}

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

3.16.9 Pod yield

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

3.16.10 Seed yield

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

3.16.11 Stover yield

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

3.16.12 Biological yield

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

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

3.16.13 Harvest index

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

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

3.17 Quality parameters

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

3.17.1 Protein content

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

3.17.2 Oil content

Inuwa *et al.* (2011) stated that, in order to determine the oil content of groundnut seed, the soxhlet extraction method (AOAC, 1990).

3.17.3 Vitamin E content

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

3.17.4 Germination percentage

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

3.18 Data analysis technique

The collected data were compiled and tabulated. Statistical analysis was done on various plant characters to find out the significance of variance. Data were analyzed using analysis of variance (ANOVA) technique with the help of computer package program MSTAT-C (software) and the mean differences were adjudged by least significant difference test (LSD) as laid out by Gomez and Gomez (1984).

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

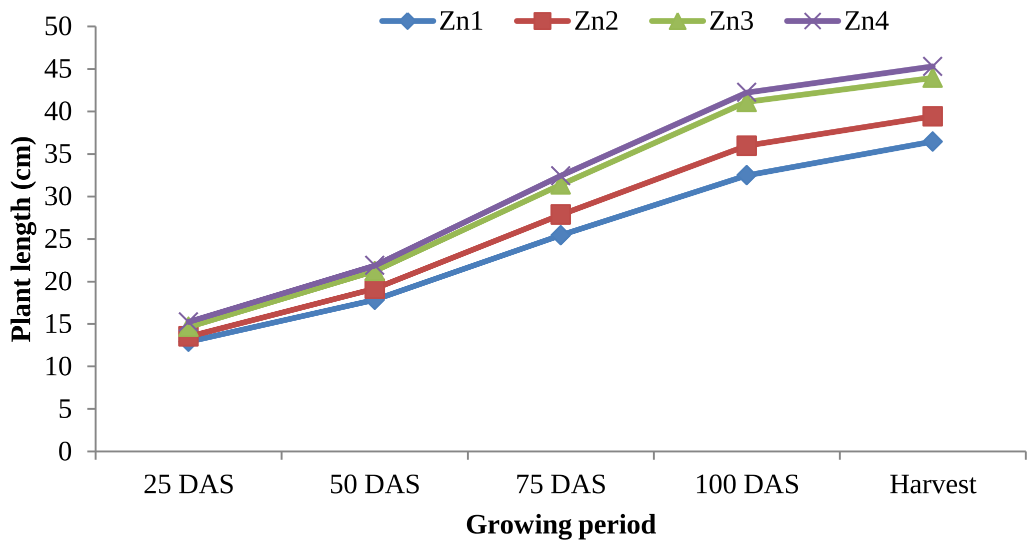
RESULTS AND DISCUSSION

The experiment was conducted to investigate the effect of zinc and boron fertilizer on growth, yield and seed quality of groundnut under the soil and agro climatic condition of Sher-e-Bangla Agricultural University, Dhaka. Data on different growth, yield and quality parameters were recorded. The analysis of variance (ANOVA) of the data on different growth and yield parameters are presented in Appendices V-X. This chapter comprises the presentation and discussion of the results obtained from the present study. The results have been presented, discussed and possible interpretations were given in tabular and graphical forms. The results obtained from the experiment have been presented under separate headings and sub-headings as follows:

4.1 Plant length

4.1.1 Effect of zinc

Plant length showed significant differences due to zinc fertilization under the present study (Figure 1). The experimental data revealed that plant length showed significant variation at 25, 50, 75, 100 DAS and at harvest due to zinc application. The longest plant (15.24, 21.87, 32.42, 42.21 and 45.28 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_4 treatment. On the other hand, the shortest plant (12.90, 17.82, 25.42, 32.48 and 36.44 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained in Zn_1 treatment. The findings of the experiment coincided with the findings of Vali *et al.* (2020) who reported that zinc fertilizer along with phosphorus fertilizer application increased the plant growth parameters *viz.*, plant length. Sharma *et al.* (2013) also reported that zinc fertilizer @ 5 kg ha^{-1} played a dominating role for vegetative growth of the plant.

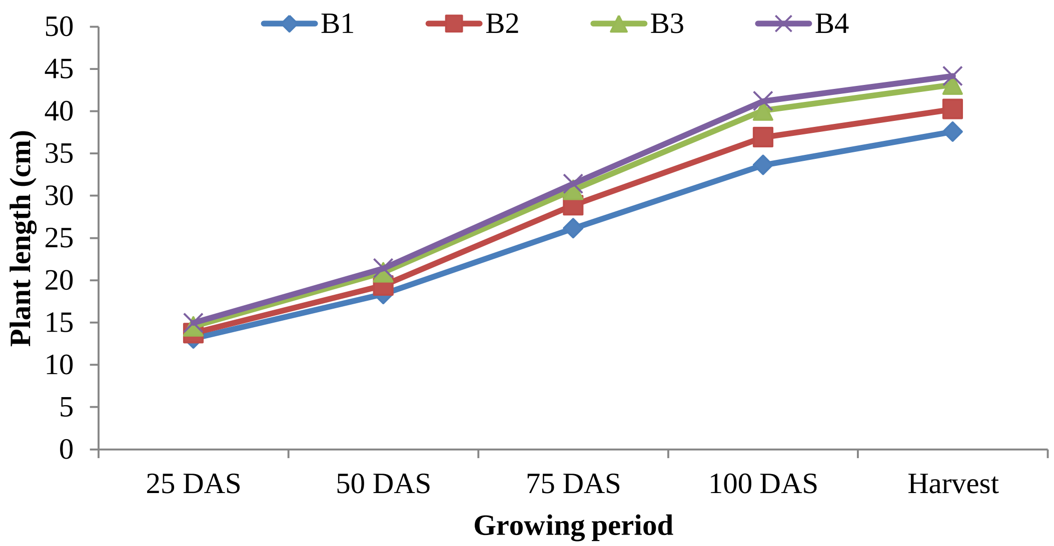


Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 1. Effect of zinc on plant length at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.50, 0.57, 0.37, 0.82 and 0.93 at 25, 50, 75, 100 DAS and at harvest, respectively).

4.1.2 Effect of foliar application of boron

Statistically significant variation on plant length of groundnut at different growth stages were observed due to foliar application of boron under the study (Figure 2). The results revealed that the longest plant (14.95, 21.40, 31.40, 41.18 and 44.15 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were observed in B_4 treatment. On the other hand, the shortest plant (13.10, 18.36, 26.13, 33.62 and 37.56 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from B_1 treatment. Similar results were also observed by Nandi *et al.* (2020) who reported that the combined spray of Zn and B at critical growth stages promoted better growth and productivity of groundnut. Poonguzhali and Pandian (2018) 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 length. The soil and foliar application of B improved the growth accompanied by increased B concentration in plant parts.



B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 2. Effect of foliar application of boron on plant length at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.26, 0.38, 0.65, 0.84 and 0.74 at 25, 50, 75, 100 DAS and at harvest, respectively).

4.1.3 Combined effect of zinc and foliar application of boron

Significant variation on plant length was observed due to combined effect of zinc and foliar application of boron (Table 1 and Appendix V). The data revealed that the longest plant length (16.67, 23.38, 34.70, 45.20 and 48.41 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 (22.68, 33.71, 44.30 and 47.09 cm at 50, 75, 100 DAS and at harvest, respectively) and Zn_3B_4 (33.52, 43.74 and 46.85 cm at 75, 100 DAS and at harvest, respectively). On the other hand, the shortest plant length (12.45, 16.51, 23.54, 28.92 and 33.75 cm at 25, 50, 75, 100 DAS and at harvest, respectively) were observed in Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 (12.72, 16.94, 25.00, 31.07 and 35.15 cm at 25, 50 DAS and at harvest, respectively); with Zn_2B_1 treatment combination at 25 and 50 DAS and with Zn_2B_2 treatment combination at 25 DAS, respectively.

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

Treatment Combinations	Plant length (cm) at				
	25 DAS	50 DAS	75 DAS	100 DAS	Harvest
Zn_1B_1	12.45 k	16.51 k	23.54 k	28.92 m	33.75 m
Zn_1B_2	12.72 jk	16.94 k	25.00 j	31.07 l	35.15 lm
Zn_1B_3	13.15 hij	18.78 hi	26.32 ghi	34.42 ij	38.15 ij
Zn_1B_4	13.28 hi	19.05 h	26.82 gh	35.54 hi	38.72 ij
Zn_2B_1	12.81 ijk	17.35 jk	25.29 ij	31.95 kl	36.23 kl
Zn_2B_2	13.00 ijk	18.00 ij	25.91 hij	33.26 jk	37.42 jk
Zn_2B_3	13.97 efg	20.42 fg	29.67 e	38.41 f	41.37 fg
Zn_2B_4	14.31 def	20.83 ef	30.56 de	40.24 e	42.63 ef
Zn_3B_1	13.43 ghi	19.65 gh	27.25 g	36.29 gh	39.50 hi
Zn_3B_2	14.48 de	21.06 def	31.70 cd	41.28 de	43.52 de
Zn_3B_3	15.18 bc	21.79 cd	33.09 b	43.09 bc	45.92 bc
Zn_3B_4	15.53 b	22.34 bc	33.52 ab	43.74 ab	46.85 ab
Zn_4B_1	13.71 fgh	19.94 g	28.45 f	37.31 fg	40.75 gh
Zn_4B_2	14.77 cd	21.48 cde	32.82 bc	42.01 cd	44.87 cd
Zn_4B_3	15.81 b	22.68 ab	33.71 ab	44.30 ab	47.09 ab
Zn_4B_4	16.67 a	23.38 a	34.70 a	45.20 a	48.41 a
$LSD_{(0.05)}$	**0.53**	**0.77**	**1.30**	**1.69**	**1.48**
CV(%)	**3.42**	**2.49**	**2.02**	**2.62**	**3.18**

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

Notes *viz:*

Zn_1= 0 kg zinc sulphate ha^{-1}

Zn_2= 2.50 kg zinc sulphate ha^{-1}

Zn_3= 5.00 kg zinc sulphate ha^{-1}

Zn_4= 7.50 kg zinc sulphate ha^{-1}

B_1= control (no boric acid L^{-1} of water)

B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1})

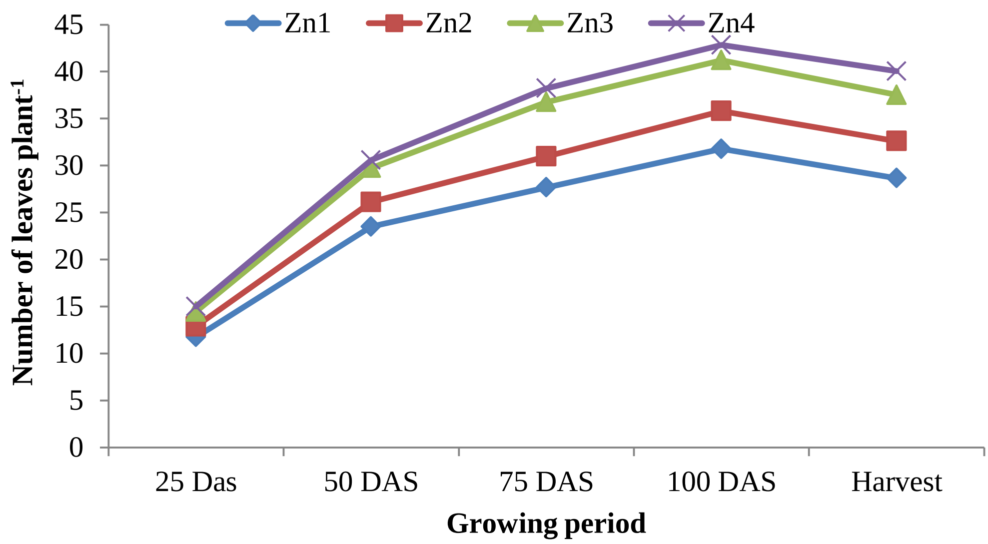
B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1})

B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

4.2 Number of leaves plant^{-1}

4.2.1 Effect of zinc

Significant effect on number of leaves plant^{-1} at different days after sowing was observed due to zinc fertilization under the present study (Figure 3). Result revealed that the maximum number of leaves plant^{-1} (14.99, 30.58, 38.21, 42.83 and 40.04 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_4 treatment. On the other hand, the minimum number of leaves plant^{-1} (11.73, 23.49, 27.66, 31.77 and 28.65 at 25, 50, 75, 100 DAS and at harvest, respectively) were observed in Zn_1 treatment. A similar result was also observed by Nakum *et al.* (2019) who reported that vegetative growth of the plant was better when was plant treated with zinc and iron fertilization than that of other treatments.

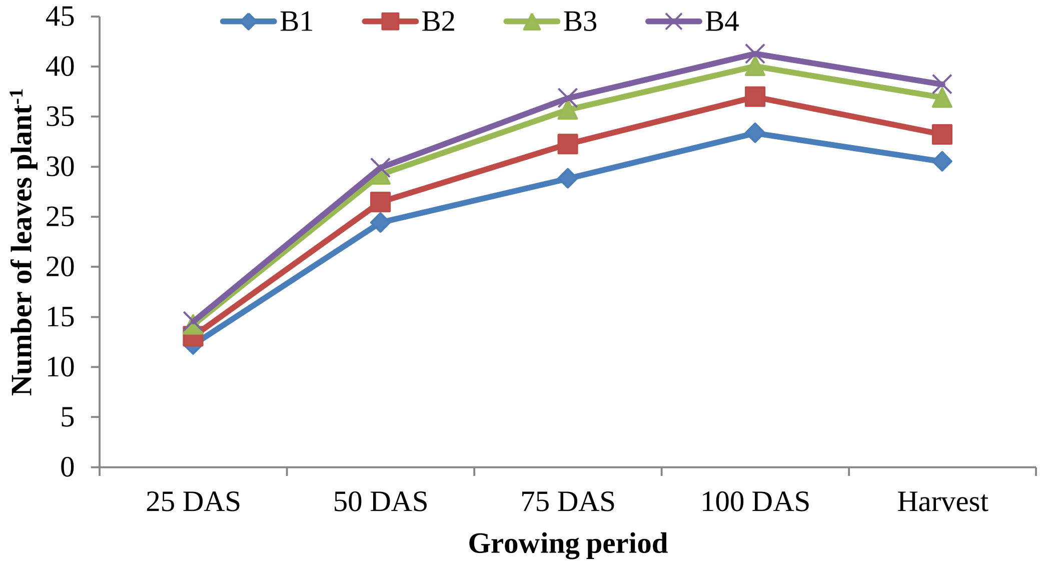


Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 3. Effect of zinc on number of leaves plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.41, 1.43, 0.97, 1.26 and 0.86 at 25, 50, 75, 100 DAS and at harvest, respectively).

4.2.2 Effect of foliar application of boron

Significant effect was observed on number of leaves plant^{-1} at different days after sowing due to foliar application of boron (Figure 4). It was revealed that the maximum number of leaves plant^{-1} (14.54, 29.88, 36.84, 41.27 and 38.21 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from B_4 treatment. On the other hand, the minimum number of leaves $plant^{-1}$ (12.23, 24.42, 28.81, 33.35 and 30.50 at 25, 50, 75, 100 DAS and at harvest, respectively) was observed in B_1 treatment. The findings of study were in coincided with the findings of Nandi *et al.* (2020) who reported that spraying of Zn and B increased plant biomass, leaf number, leaf area, chlorophyll content noticeably and with the increase in concentration of Zn and B in spray, the increment became quite intense.



B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 4. Effect of foliar application of boron on number of leaves $plant^{-1}$ at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.24, 0.54, 0.74, 0.89 and 0.89 at 25, 50, 75, 100 DAS and at harvest, respectively).

4.2.3 Combined effect of zinc and foliar application of boron

Significant variation was marked for number of leaves $plant^{-1}$ of groundnut due to combined effect of zinc and foliar application of boron (Table 2 and Appendix VI). Experimental data revealed that the maximum number of leaves $plant^{-1}$ (16.00, 32.67, 42.50, 46.33 and 44.67 at 25, 50, 75, 100 DAS and at harvest, respectively) were achieved from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 treatment combination at 25, 50, 75 and 100 DAS, respectively. On the other hand, the minimum number of leaves $plant^{-1}$ (10.75, 20.33, 25.50, 29.75 and 26.33 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 treatment combination at 25, 75, 100 DAS and at harvest, respectively; with Zn_2B_1 treatment combination at 100 DAS.

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

Treatment Combinations	Number of leaves plant^{-1} at				
	25 DAS	**50 DAS**	**75 DAS**	**100 DAS**	**Harvest**
Zn_1B_1	10.75 l	20.33 l	25.50 l	29.75 l	26.33 l
Zn_1B_2	11.00 l	21.33 kl	26.33 kl	30.67 kl	27.50 kl
Zn_1B_3	12.50 ij	26.00 ij	29.33 hij	33.00 ij	30.00 ij
Zn_1B_4	12.67 i	26.33 i	29.50 hi	33.67 hi	30.75 i
Zn_2B_1	11.67 k	22.67 k	27.75 jk	31.33 jkl	28.67 jk
Zn_2B_2	12.00 jk	24.50 j	28.67 ij	32.50 ijk	29.33 ij
Zn_2B_3	13.67 fg	28.33 fgh	32.75 f	38.67 f	35.75 fg
Zn_2B_4	14.15 ef	29.00 efg	34.67 e	40.75 e	36.67 f
Zn_3B_1	13.00 hi	27.00 hi	30.67 gh	35.33 gh	32.67 h
Zn_3B_2	14.50 e	29.75 def	36.33 d	41.67 de	37.33 ef
Zn_3B_3	15.00 cd	30.75 bcd	39.33 c	43.50 bc	39.33 cd
Zn_3B_4	15.33 bc	31.50 abc	40.67 bc	44.33 bc	40.75 bc
Zn_4B_1	13.50 gh	27.67 ghi	31.33 fg	37.00 fg	34.33 gh
Zn_4B_2	14.72 de	30.25 cde	37.67 d	43.00 cd	38.67 de
Zn_4B_3	15.75 ab	31.75 ab	41.33 ab	45.00 ab	42.50 b
Zn_4B_4	16.00 a	32.67 a	42.50 a	46.33 a	44.67 a
$LSD_{(0.05)}$	**0.49**	**1.08**	**1.49**	**1.78**	**1.78**
CV(%)	**2.19**	**2.33**	**2.65**	**2.79**	**3.06**

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

Notes *viz:*

Zn_1= 0 kg zinc sulphate ha^{-1}

Zn_2= 2.50 kg zinc sulphate ha^{-1}

Zn_3= 5.00 kg zinc sulphate ha^{-1}

Zn_4= 7.50 kg zinc sulphate ha^{-1}

B_1= control (no boric acid L^{-1} of water)

B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1})

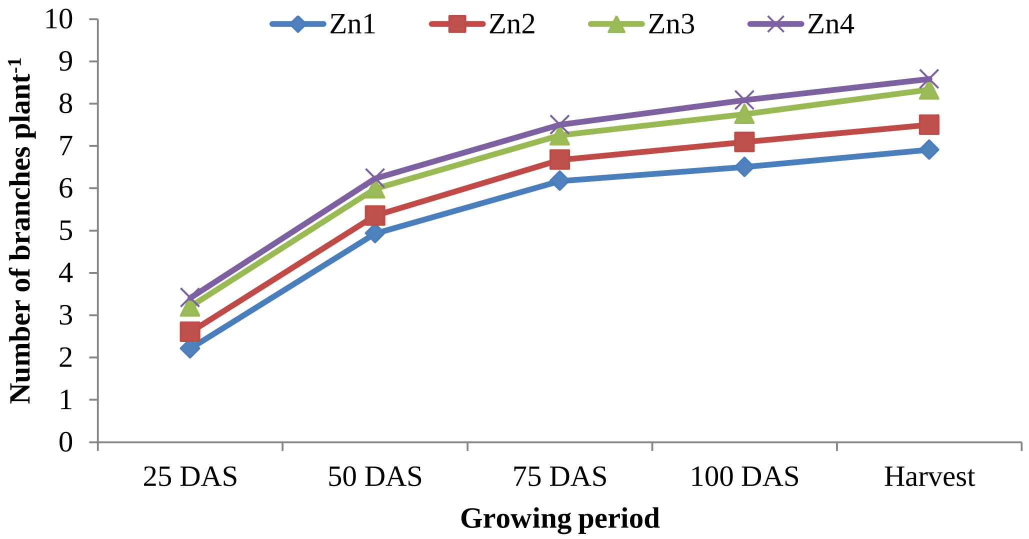
B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1})

B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

4.3 Number of branches plant^{-1}

4.3.1 Effect of zinc

Significant effect on number of branches plant^{-1} at different days after sowing was observed due to zinc under the present study (Figure 3). Result revealed from the study that the maximum number of branches plant^{-1} (3.41, 6.23, 7.50, 8.08 and 8.58 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_4 treatment. On the other hand, the minimum number of branches plant^{-1} (2.21, 4.93, 6.17, 6.50 and 6.91 at 25, 50, 75, 100 DAS and at harvest, respectively) were observed in Zn_1 treatment. Similar trend also found by El-Habbasha *et al.* (2013) who reported that groundnut treatment with 40 kg N fed^{-1} + Zn foliar application at seed filling stage recorded the highest significant values of most studied characters than the other treatments followed by the same nitrogen level and Zn foliar application at flowering stage. Sharma *et al.* (2013) reported that application of zinc fertilizer @ 5 kg ha^{-1} exerted significant effects on plant growth parameters, root development, photosynthesis, yield contributing characters and pod yield of the crop.

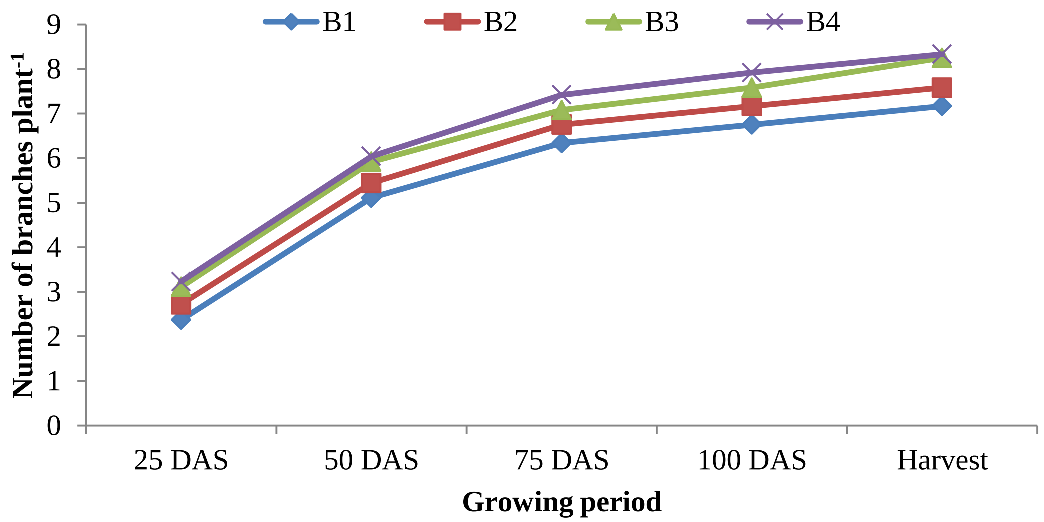


Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 5. Effect of zinc on number of branches plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.20, 0.13, 0.13, 0.26 and 0.24 at 25, 50, 75, 100 DAS and at harvest, respectively).

4.3.2 Effect of foliar application of boron

Significant variation was observed on number of branches plant^{-1} at different days after sowing due to foliar application of boron (Figure 4). Experimental data revealed that the maximum number of branches plant^{-1} (3.23, 6.04, 7.42, 7.92 and 8.33 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from B_4 treatment which was statistically similar with B_3 at harvest. On the other hand, the minimum number of branches plant^{-1} (2.37, 5.11 6.34, 6.75 and 7.17 at 25, 50, 75, 100 DAS and at harvest, respectively) was observed in B_1 treatment. The result of the experiment coincided with the findings of Quamruzzaman *et al.* (2016) reported that days to first-last emergence and days to first-50% lowering took shorter times and vegetative growth, pods dry weight plant^{-1}, pod yield, and germination were markedly increased with the application of boron.



B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 6. Effect of foliar application of boron on number of branches plant^{-1} at different days after sowing (DAS) of groundnut ($LSD_{0.05}$= 0.08, 0.09, 0.14, 0.17 and 0.17 at 25, 50, 75, 100 DAS and at harvest, respectively).

4.3.3 Combined effect of zinc and foliar application of boron

Significant variation was observed for number of branches plant^{-1} of groundnut due to combined effect of zinc and foliar application of boron (Table 3 and Appendix VII). Experimental data revealed that the maximum number of branches plant^{-1} (3.83, 6.67, 8.00, 8.67 and 9.33 at 25, 50, 75, 100 DAS and at harvest, respectively) were achieved from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 treatment combination at 25, 50, 100 DAS and at harvest, respectively. On the other hand, the minimum number of branches plant^{-1} (1.93, 4.50, 5.67, 6.00 and 6.33 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 treatment combination at 25, 50, 100 DAS and at harvest, respectively; with Zn_2B_1 treatment combination at 25 DAS, respectively.

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

Treatment Combinations	Number of branches plant^{-1} at				
	25 DAS	50 DAS	75 DAS	100 DAS	Harvest
Zn_1B_1	1.93 k	4.50 k	5.67 h	6.00 h	6.33 i
Zn_1B_2	2.00 k	4.67 jk	6.00 g	6.33 gh	6.67 hi
Zn_1B_3	2.42 j	5.23 h	6.33 f	6.67 fg	7.33 fg
Zn_1B_4	2.50 ij	5.33 h	6.67 e	7.00 ef	7.33 fg
Zn_2B_1	2.07 k	4.83 ij	6.00 g	6.67 fg	7.00 gh
Zn_2B_2	2.33 j	5.00 i	6.33 f	6.67 fg	7.00 gh
Zn_2B_3	2.93 fg	5.75 g	7.00 d	7.33 de	8.00 de
Zn_2B_4	3.07 ef	5.83 fg	7.33 c	7.67 cd	8.00 de
Zn_3B_1	2.67 hi	5.42 h	6.67 e	7.00 ef	7.67 ef
Zn_3B_2	3.21 de	6.00 ef	7.33 c	7.67 cd	8.33 cd
Zn_3B_3	3.42 c	6.21 cd	7.33 c	8.00 bc	8.67 bc
Zn_3B_4	3.50 bc	6.33 bc	7.67 b	8.33 ab	8.67 bc
Zn_4B_1	2.80 gh	5.67 g	7.00 d	7.33 de	7.67 ef
Zn_4B_2	3.33 cd	6.07 de	7.33 c	8.00 bc	8.33 cd
Zn_4B_3	3.67 ab	6.50 ab	7.67 b	8.33 ab	9.00 ab
Zn_4B_4	3.83 a	6.67 a	8.00 a	8.67 a	9.33 a
$LSD_{(0.05)}$	**0.16**	**0.19**	**0.28**	**0.34**	**0.34**
CV(%)	**3.39**	**2.08**	**2.46**	**2.79**	**2.63**

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.

Notes *viz:*

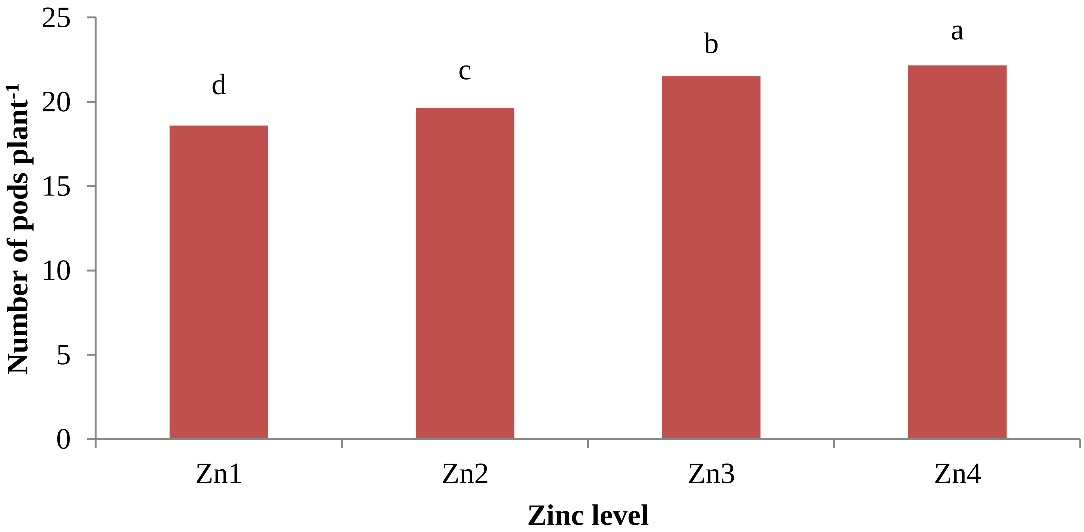
Zn_1= 0 kg zinc sulphate ha^{-1}
Zn_2= 2.50 kg zinc sulphate ha^{-1}
Zn_3= 5.00 kg zinc sulphate ha^{-1}
Zn_4= 7.50 kg zinc sulphate ha^{-1}

B_1= control (no boric acid L^{-1} of water)
B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1})
B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1})
B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

4.4 Number of pods plant^{-1}

4.4.1 Effect of zinc

Groundnut exerted significant variation on number of pods plant^{-1} due to the effect of zinc under the study (Figure 7). It was revealed that the maximum number of pods plant^{-1} (22.16) was obtained from Zn_4 treatment. On the other hand, the minimum number of pods plant^{-1} (18.60) was observed in Zn_1 treatment. The result of the experiment coincided with the findings of El-Habbasha *et al.* (2013) who reported that increasing the use of Zn foliar application either at flowering or seed filling stages significantly increased number of pods plant^{-1}, weight of pods plant^{-1}, number of seeds plant^{-1}, weight of seeds plant^{-1} and 100-pod weight compared to the control treatment.



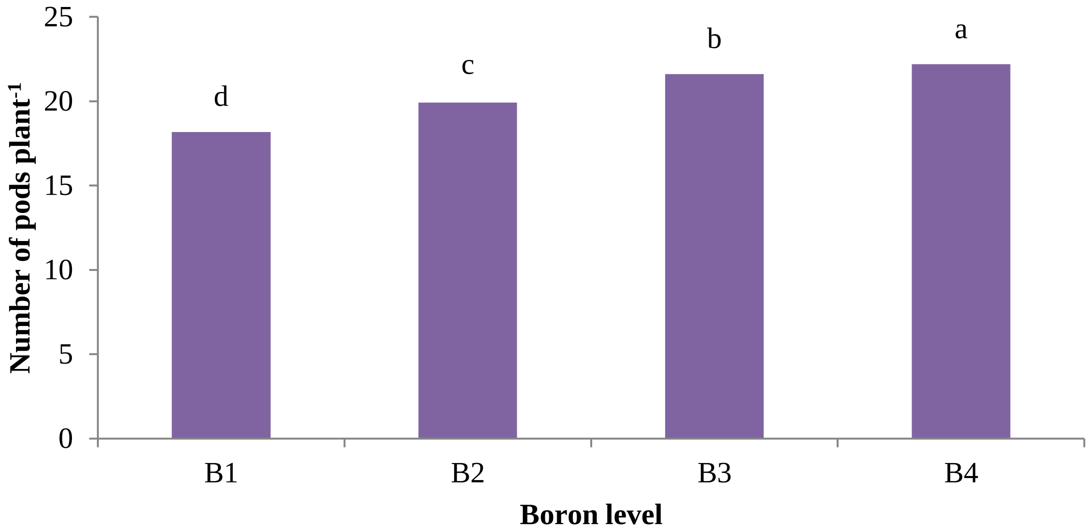
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 7. Effect of zinc on number of pods plant^{-1} of groundnut ($LSD_{0.05}$= 0.45).

4.4.2 Effect of foliar application of boron

Number of pods plant^{-1} of groundnut showed significant variation due to foliar application of boron (Figure 8). The data revealed that the maximum number of pods plant^{-1} (22.19) was achieved from B_4 treatment. On the other hand, the minimum number of pods plant^{-1} (18.18) was obtained from B_1 treatment. A similar result was also observed by Quamruzzaman *et al.* (2016) reported that number of pods plant^{-1}, pods dry weight plant^{-1}, pod yield, and germination increased markedly with the application of boron. Kabir *et al.* (2013) also reported that the combined application of fertilizer P, Ca and B increased the most vital yield contributing parameter number of pods plant^{-1} for obtaining the highest yield of groundnut.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 8. Effect of foliar application of boron on number of pods plant^{-1} of groundnut ($LSD_{0.05}$= 0.52).

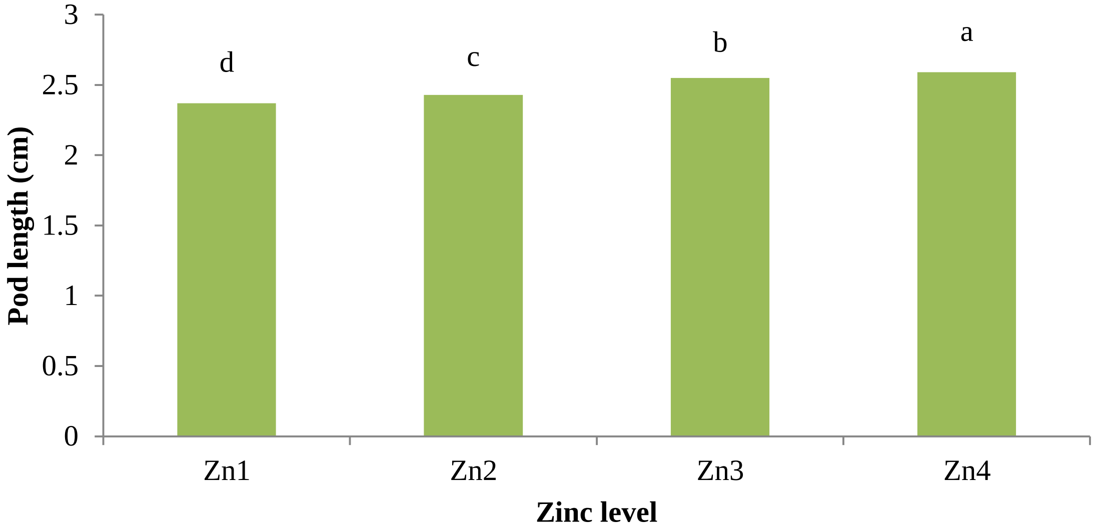
4.4.3 Combined effect of zinc and foliar application of boron

Significant difference was observed for number of pods plant^{-1} of groundnut due to combined effect of zinc fertilizer and foliar application of boron (Table 4 and Appendix VIII). It was revealed that the maximum number of pods plant^{-1} (23.87) was observed in Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 (23.25) and Zn_3B_4 (22.92) treatment combination. On the other hand, the minimum number of pods plant^{-1} (16.76) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 (17.39) and Zn_2B_1 (17.77) treatment combinations.

4.5 Pod length

4.5.1 Effect of zinc

Pod length was significantly influenced by zinc fertilization under the present study (Figure 9). Experimental data revealed that the maximum pod length (2.59 cm) was obtained from Zn_4 treatment while the minimum pod length (2.37 cm) was observed from Zn_1 treatment. Similar result was observed by Sabra *et al.* (2019) who reported that yield attributes (pod length, number of pods plant^{-1}, number of seed plant^{-1}, weight of pods plant^{-1} and seed weight plant^{-1} and 100 seed weight) were affected significantly due to foliar spraying with micronutrient treatments.



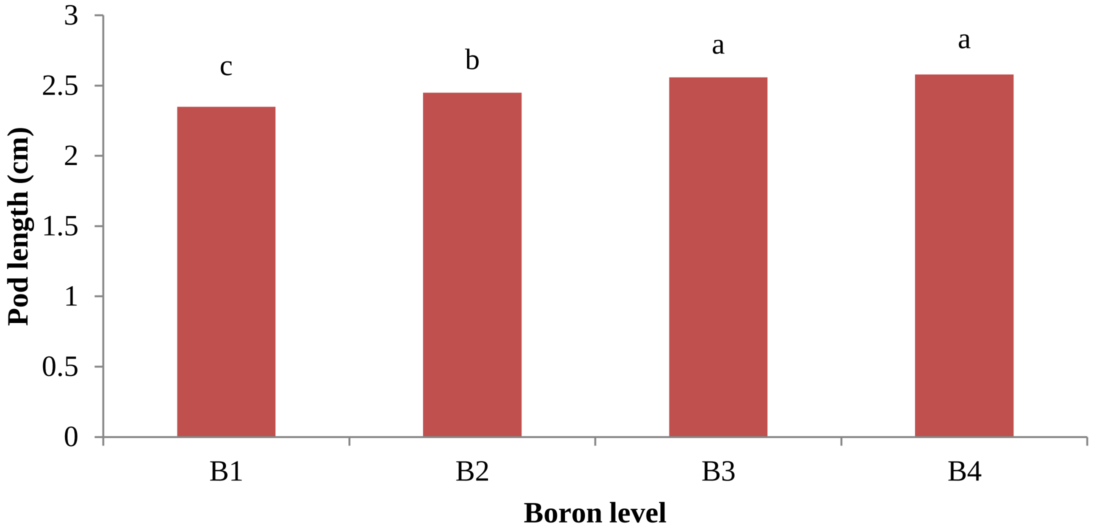
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 9. Effect of zinc on pod length of groundnut ($LSD_{0.05}$= 0.02).

4.5.2 Effect of Effect of foliar application of boron

Significant variation on pod length of groundnut was observed due to foliar application of boron under the experiment (Figure 10). Experimental data showed that the maximum pod length was observed in B_4 (2.58 cm) treatment which was statistically similar to B_3 (2.56 cm) treatment while the minimum pod length was obtained from B_1 (2.35 cm) treatment. The result of the study coincided with the findings of Nandi *et al.* (2020) reported that spraying of Zn and B increased plant growth parameters and yield contributing characters noticeably and with the increase in concentration of Zn and B in spray, the increment became quite intense. The combined spray of Zn and B at critical growth stages promoted better growth and productivity of groundnut.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 10. Effect of foliar application of boron on pod length of groundnut ($LSD_{0.05}$= 0.02).

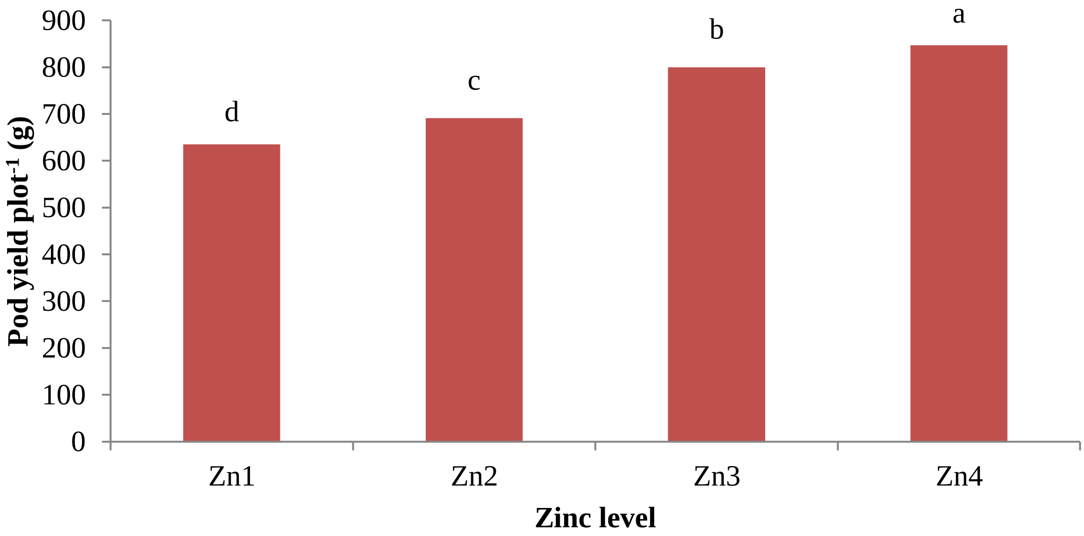
4.5.3 Combined effect of zinc and foliar application of boron

Combined effect of zinc fertilizer and foliar application of boron showed significant influence on pod length of groundnut under the experiment (Table 4 and Appendix VIII). Result revealed that the maximum pod length (2.70 cm) was obtained from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 (2.67 cm) treatment combination. On the other hand, the minimum pod length of groundnut (2.27 cm) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 (2.30 cm) and Zn_2B_1 (2.32 cm) treatment combinations.

4.6 Pod yield plot^{-1}

4.6.1 Effect of zinc

Significant variation was recorded for pod yield plot^{-1} by different zinc levels of groundnut (Figure 11). The highest pod yield (847.00 g) plot^{-1} was recorded from Zn_4 treatment, whereas the lowest pod yield (635.00 g) plot^{-1} was recorded from Zn_1 treatment. A similar result also found by Sabra *et al.* (2019) who revealed that combination of Zn + Mn + B surpassed the control. The interaction effect between groundnut varieties and micronutrient foliar application revealed a high significant difference for all the studied traits. Yield attributes (number of pods plant^{-1}, number of seed plant^{-1}, weight of pods plant^{-1} and seed weight plant^{-1}, 100-seed weight and pod yield per plot) were affected significantly due to foliar spraying with micronutrient treatments.



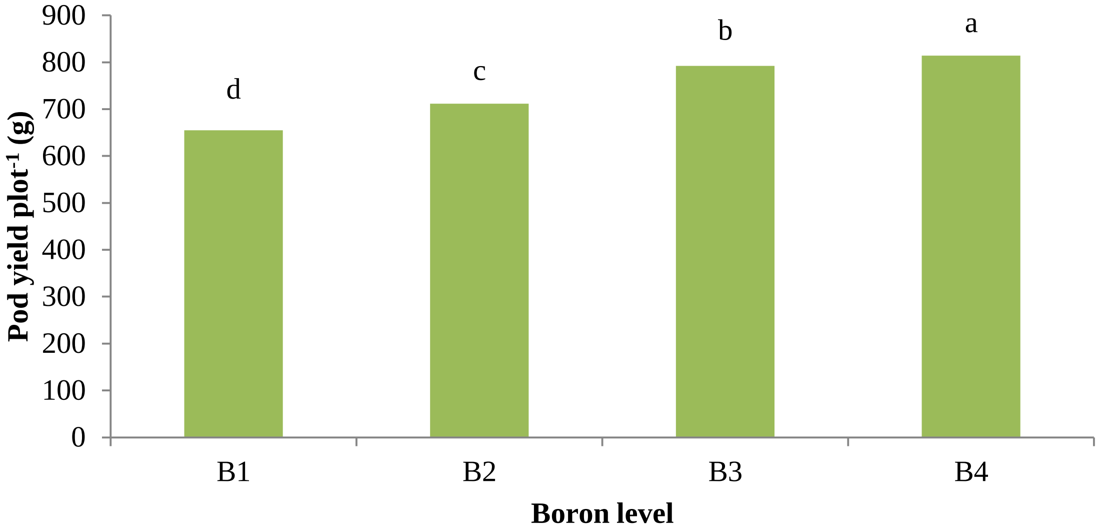
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 11. Effect of zinc on pod yield plot^{-1} of groundnut ($LSD_{0.05}$= 19.57).

4.6.2 Effect of foliar application of boron

Statistically significant influence was found on pod yield plot^{-1} of groundnut persuaded by foliar application of boron (Figure 12). The highest pod yield plot^{-1} (814.00 g) was recorded from B_4 treatment. On the other hand, the lowest pod yield plot^{-1} (655.00 g) was recorded from B_1 treatment. The result of the experiment was also coincided with the findings of El-Kader and Mona (2013) who reported that application of S and foliar spraying with micronutrient (Zn and B) together had the significant effect on peanut pod and seed yield and its attributes as well as seed quality.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 12. Effect of foliar application of boron on pod yield plot^{-1} of groundnut ($LSD_{0.05}$= 15.22).

4.6.3 Combined effect of zinc and foliar application of boron

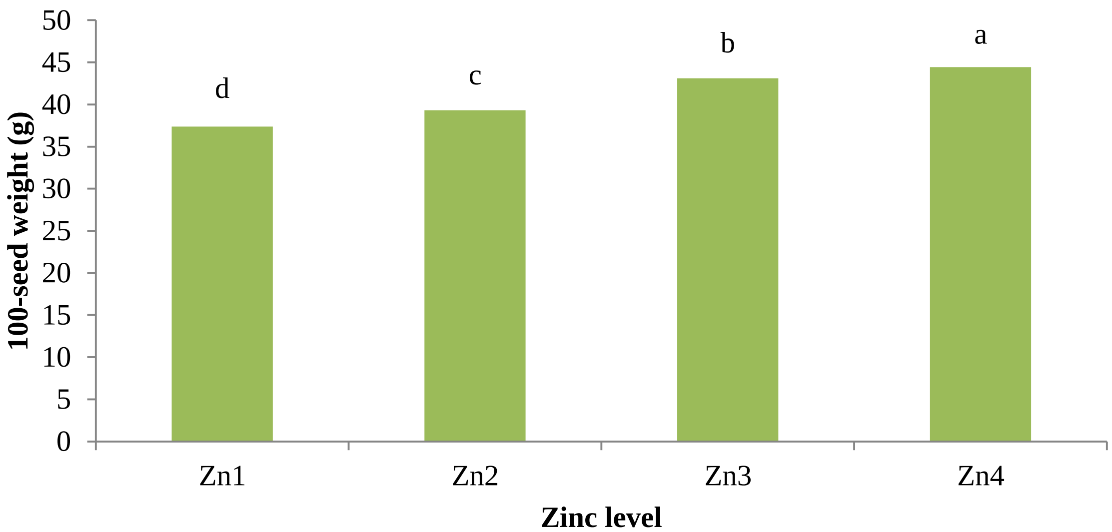
Pod yield plot^{-1} of groundnut was affected significantly due to treatment combination of zinc and foliar application of boron (Table 4 and Appendix VIII). Results showed that the treatment combination of Zn_4B_4 gave the highest pod yield plot^{-1} (936.00 g) followed by Zn_4B_3, whereas Zn_1B_1 gave the lowest pod yield plot^{-1} (572.00 g) which was statistically similar with Zn_1B_2 treatment combination.

4.7 100 seeds weight

4.7.1 Effect of zinc

Zinc showed significant influence on 100 seeds weight of groundnut (Figure 13). It was revealed that the maximum 100 seeds weight of groundnut (44.45 g) was obtained from Zn_4 treatment while the minimum 100 seeds weight of groundnut

(37.38 g) was obtained from Zn_1 treatment. Similar trends were also observed by Sabra *et al.* (2019) who reported that combination of Zn + Mn + B surpassed over all treatments and control. The interaction effect between groundnut varieties and micronutrient foliar application revealed a high significant difference for all studied traits. Yield attributes (number of pods plant^{-1}, number of seed plant^{-1}, weight of pods plant^{-1} and seed weight plant^{-1} and 100-seed weight) were affected significantly due to foliar spraying with micronutrient treatments. El-Habbasha *et al.* (2013) revealed that increasing the use of Zn foliar application either at flowering or seed filling stages significantly increased number of pods plant^{-1}, weight of pods plant^{-1}, number of seeds plant^{-1}, weight of seeds plant^{-1}, 100-pod weight compared to control treatment.



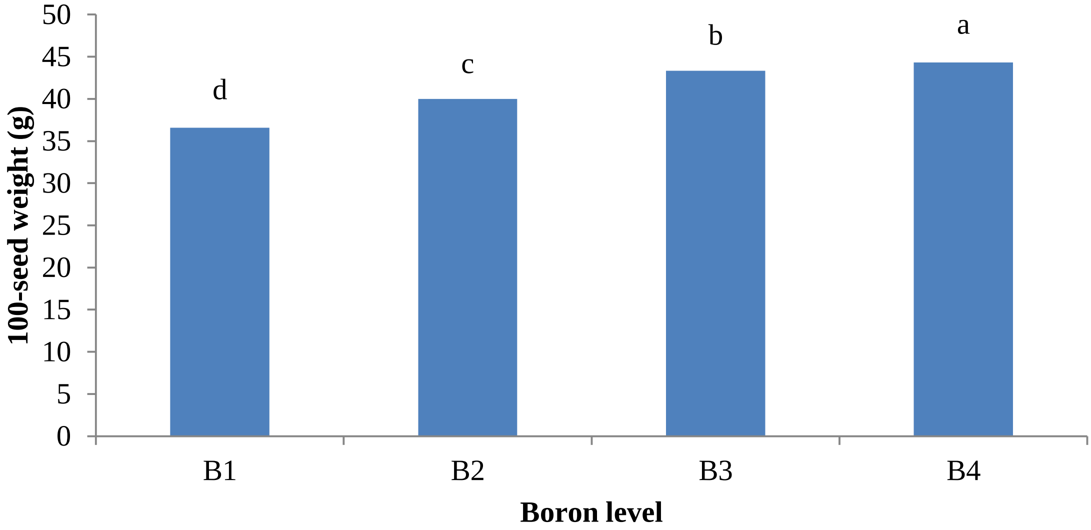
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 13. Effect of zinc on 100-seed weight of groundnut ($LSD_{0.05}$= 1.25).

4.7.2 Effect of foliar application of boron

Significant effect was observed for 100-seed weight of groundnut due to foliar application of boron (Figure 14). It was showed that the maximum 100-seed weight of groundnut was obtained from B_4 (44.33 g) treatment. On the other hand, the minimum 100-seed weight of groundnut was obtained from B_1 (36.56 g) treatment. Nandi *et al.* (2020) reported that foliar spray of Zn and B jointly increased the 100 seeds weight also the pod yield, respectively. Mekdad (2019) also revealed that among three foliar spray of boron levels (B_0: tap water, B_1: 100 ppm and B_2: 150 ppm) on peanut results indicated that yield components, yield and its quality of peanut were positively ($P \leq 0.01$) affected by the 150 ppm.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 14. Effect of foliar application of boron on 100-seed weight of groundnut ($LSD_{0.05}$= 0.94).

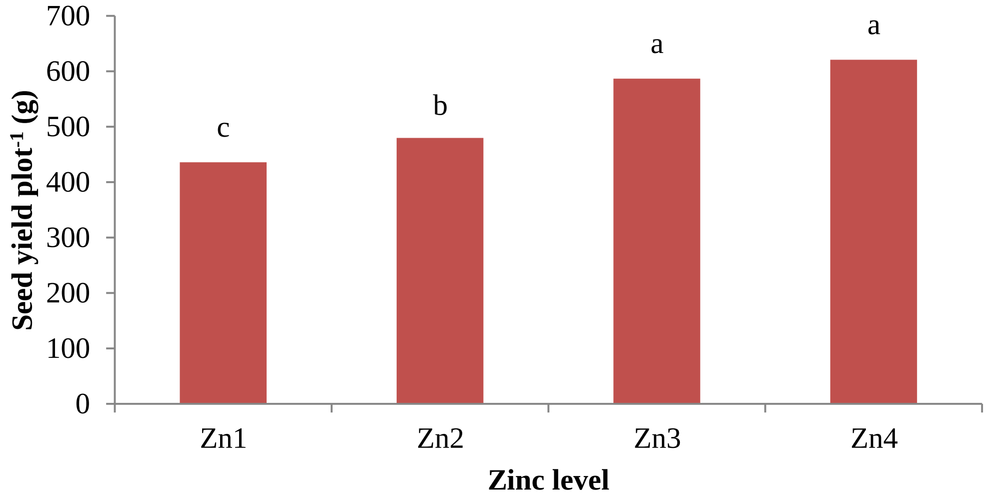
4.7.3 Combined effect of zinc and foliar application of boron

Combined effect of zinc and foliar application of boron showed significant variation on 100-seed weight of groundnut under the present study (Table 4 Appendix VIII). Result revealed that the maximum 100-seed weight of groundnut (47.83 g) was observed in Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 (46.62 g) and Zn_3B_4 (45.92 g) treatment combination. On the other hand, the minimum 100 seeds weight of groundnut (34.18 g) was observed in Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 (34.95 g) and Zn_2B_1 (35.81 g) treatment combinations.

4.8 Seed yield plot^{-1}

4.8.1 Effect of zinc

Significant variation was recorded for seed yield plot^{-1} by different zinc levels of groundnut (Figure 15). The highest seed yield plot^{-1} (621.00 g) was recorded from Zn_4 treatment, whereas which was statistically identical to Zn_3 treatment while the lowest seed yield plot^{-1} (436.00 g) was recorded from Zn_1 treatment. Similar result also found by Sabra *et al.* (2019) who revealed that combination of Zn + Mn + B surpassed the control treatment. Yield attributes were affected significantly due to foliar spraying with micronutrient treatments.



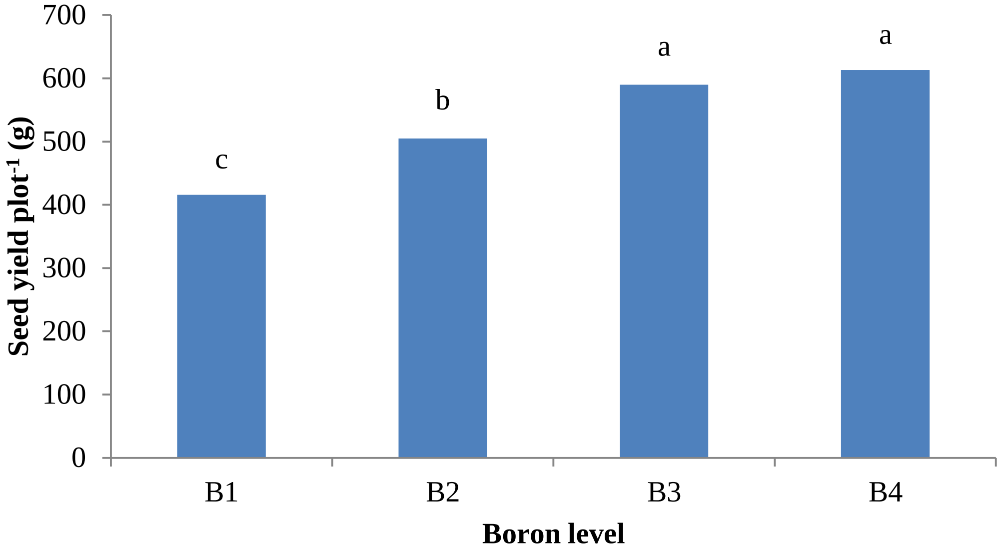
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 15. Effect of zinc on seed yield plot^{-1} of groundnut ($LSD_{0.05}$= 39.09).

4.8.2 Effect of foliar application of boron

Statistically significant influence was found on seed yield plot^{-1} of groundnut persuaded by foliar application boron (Figure 16). The highest seed yield plot^{-1} (613.00 g) was recorded from B_4 treatment which was statistically identical to B_3 treatment. On the other hand, the lowest seed yield plot^{-1} (416.00 g) was recorded from B_1 treatment. The result of the experiment was also coincided with the findings of El-Kader and Mona (2013) who reported that application of S and foliar spraying with micronutrient (Zn and B) together had the significant effect on peanut seed yield and its attributes as well as seed quality.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 16. Effect of foliar application of boron on seed yield plot^{-1} of groundnut ($LSD_{0.05}$= 27.09).

4.8.3 Combined effect of zinc and foliar application of boron

Seed yield plot^{-1} of groundnut was significantly influenced due to treatment combination of zinc and foliar application of boron (Table 4 and Appendix VIII). The data showed that the treatment combination of Zn_4B_4 gave the highest seed yield plot^{-1} (712.00 g) followed by Zn_4B_3 and Zn_3B_4 treatment combinations whereas Zn_1B_1 gave the lowest seed yield plot^{-1} (360.00 g) which was statistically similar with Zn_1B_2 and Zn_2B_1 treatment combinations.

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

Treatment Combinations	Number of pods plant^{-1}	Pod length (cm)	Pod yield plot^{-1} (g)	100-seed weight (g)	Seed yield plot^{-1} (g)
Zn_1B_1	16.76 k	2.27 l	572.00 l	34.18 l	360.00 l
Zn_1B_2	17.39 jk	2.30 l	600.00 kl	34.95 kl	384.00 kl
Zn_1B_3	19.72 gh	2.45 gh	676.00 hi	39.67 h	488.00 ghi
Zn_1B_4	20.53 fg	2.47 fgh	692.00 gh	40.73 gh	512.00 fgh
Zn_2B_1	17.77 jk	2.32 kl	620.00 jk	35.81 jkl	400.00 kl
Zn_2B_2	18.33 ij	2.36 jk	648.00 ij	36.62 jk	424.00 jk
Zn_2B_3	21.00 ef	2.50 fg	736.00 ef	41.92 fg	536.00 efg
Zn_2B_4	21.47 def	2.52 ef	760.00 de	42.85 ef	560.00 def
Zn_3B_1	18.85 hi	2.38 ij	708.00 fgh	37.51 ij	440.00 ijk
Zn_3B_2	21.82 de	2.56 de	780.00 d	43.75 def	592.00 de
Zn_3B_3	22.47 bcd	2.60 cd	844.00 bc	45.18 bcd	648.00 bc
Zn_3B_4	22.92 abc	2.64 bc	868.00 b	45.92 abc	668.00 abc
Zn_4B_1	19.37 h	2.42 hi	720.00 fg	38.75 hi	464.00 hij
Zn_4B_2	22.15 cd	2.58 d	820.00 c	44.61 cde	620.00 cd
Zn_4B_3	23.25 ab	2.67 ab	912.00 a	46.62 ab	688.00 ab
Zn_4B_4	23.87 a	2.70 a	936.00 a	47.83 a	712.00 a
$LSD_{(0.05)}$	**1.04**	**0.05**	**30.45**	**1.88**	**54.18**
CV(%)	**3.03**	**1.36**	**2.43**	**2.72**	**6.06**

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

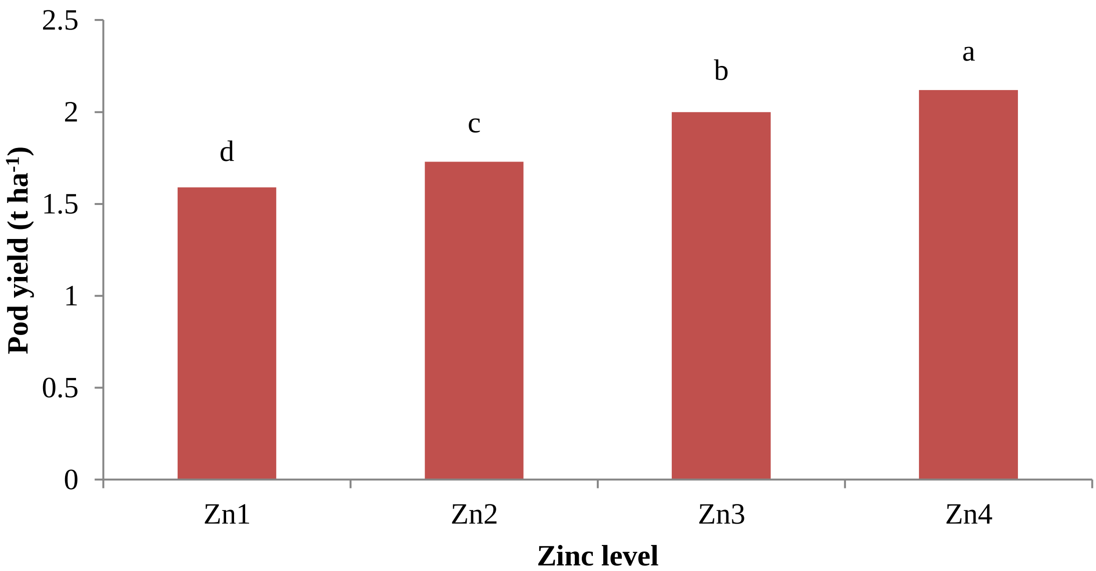
Notes *viz:*

Zn_1= 0 kg zinc sulphate ha^{-1}	B_1= control (no boric acid L^{-1} of water)
Zn_2= 2.50 kg zinc sulphate ha^{-1}	B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1})
Zn_3= 5.00 kg zinc sulphate ha^{-1}	B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1})
Zn_4= 7.50 kg zinc sulphate ha^{-1}	B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

4.9 Pod yield

4.9.1 Effect of zinc

Significant variation on pod yield (t ha^{-1}) of groundnut was observed due to effect of different zinc levels (Figure 17). It was revealed that the maximum pod yield (2.12 t ha^{-1}) was obtained from Zn_4 treatment while the minimum pod yield (1.59 t ha^{-1}) was obtained from Zn_1 treatment. The result of the experiment was also in coincided by Al-Yasari and Al-Yasari (2022) who reported that nano-zinc (100 mg L^{-1}) foliar application led to a significant increase in the pod yield with increased rates of 21.2% compared with the control. Vali *et al.* (2020) reported that the treatment receiving 50 kg phosphorus + 30 kg zinc ha^{-1} produced significantly a higher pod yield. Tathe *et al.* (2008) reported that zinc application, 40 kg Zn ha^{-1} recorded significantly the highest pod yield, protein content and zinc uptake by groundnut, whereas application of 20 kg Zn ha^{-1} recorded the highest oil content and sulphur uptake by groundnut. Saha *et al.* (2015) reported that integrated mode of application of Zn, B and S showed a positive interaction as the yield increased with their uptake in groundnut.



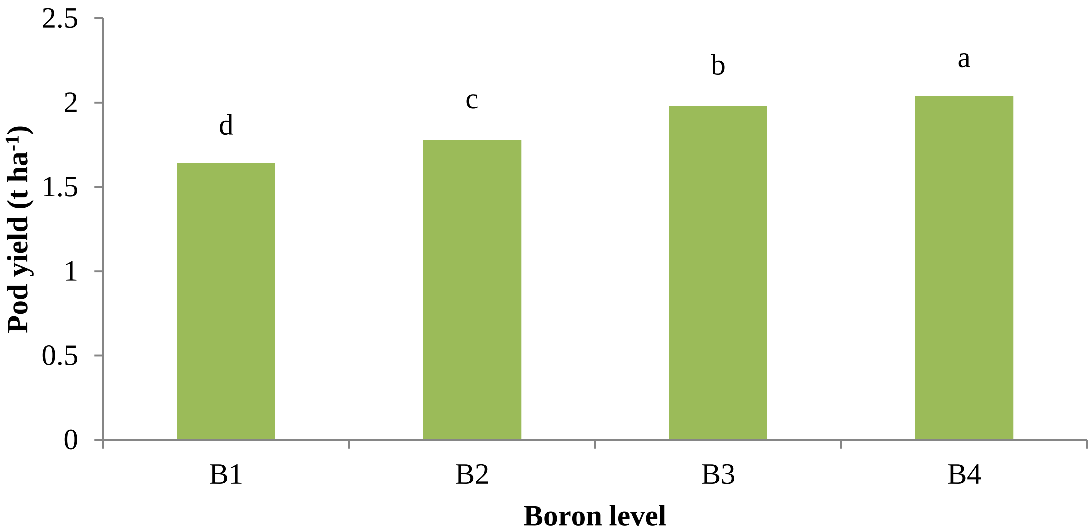
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 17. Effect of zinc on pod yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.04).

4.9.2 Effect of foliar application of boron

Foliar application of boron exerted significant variation on pod yield (t ha^{-1}) of groundnut under this experiment (Figure 18). It was showed that the maximum pod yield of groundnut was obtained from B_4 (2.04 t ha^{-1}) treatment. On the other hand, the minimum pod yield of groundnut was obtained from B_1 (1.64 t ha^{-1}) treatment. The finding of the experiment was coincided with the findings of Quamruzzaman *et al.* (2016) revealed that pod yield and germination were markedly increased with the application of boron. Mekdad (2019) who reported that among the three foliar spray with boron levels (B_0: tap water, B_1: 100 ppm and B_2: 150 ppm) on peanut the experimental results indicated that yield components, yield and its quality of peanut were positively ($P \leq 0.01$) affected by foliar application of boron (B_2). Kabir *et al.* (2013) also reported that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 18. Effect of foliar application of boron on pod yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.05).

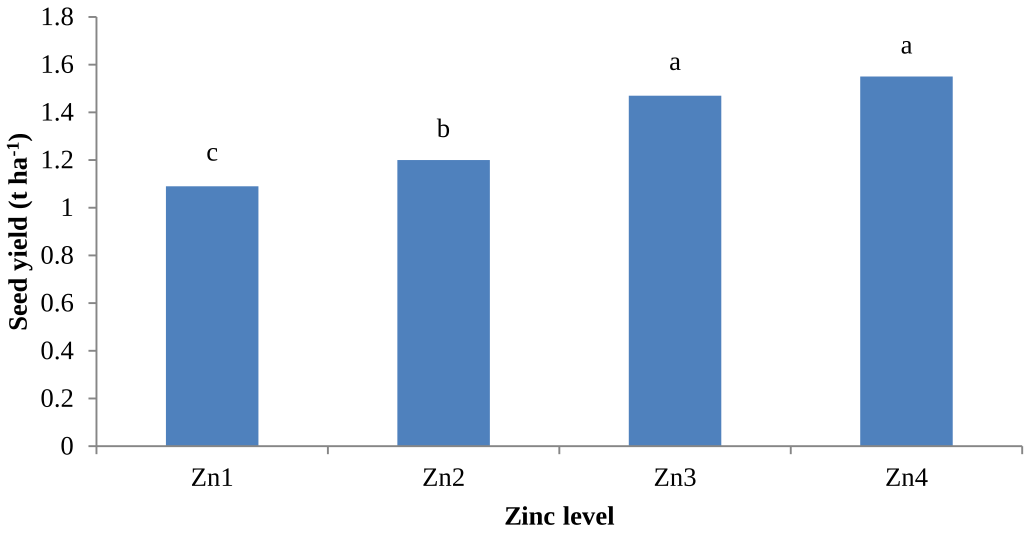
4.9.3 Combined effect of zinc and foliar application of boron

Combined effect of zinc and foliar application of boron showed significant difference on pod yield of groundnut under the present study (Table 5 Appendix IX). It was revealed that the maximum pod yield of groundnut (2.34 t ha^{-1}) was obtained from Zn_4B_4 treatment combination which was statistically as par with Zn_4B_3 (2.28 t ha^{-1}) treatment combination. On the other hand, the minimum pod yield of groundnut (1.43 t ha^{-1}) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 (1.50 t ha^{-1}) treatment combination.

4.10 Seed yield

4.10.1 Effect of zinc

Significant variation on seed yield (t ha^{-1}) of groundnut was observed due to effect of different zinc levels (Figure 19). Experimental data revealed that the maximum seed yield (1.55 t ha^{-1}) was obtained from Zn_4 treatment which was statistically similar with Zn_3 treatment while the minimum seed yield (1.09 t ha^{-1}) was obtained from Zn_1 treatment. The result of the experiment was also in coincided by Tathe *et al.* (2008) reported that zinc application, 40 kg Zn ha^{-1} recorded significantly the highest pod yield, seed yield, protein content and zinc uptake by groundnut whereas application of 20 kg Zn ha^{-1} recorded the highest oil content and sulphur uptake by groundnut. Saha *et al.* (2015) reported that integrated mode of application of Zn, B and S showed a positive interaction as yield increase with their uptake in groundnut. Maharnor *et al.* (2018) also revealed that application of Zn along with recommended dose of NPK to different cultivars was found to be beneficial in increasing yield and quality of groundnut over control on low zinc containing inceptisol soil.



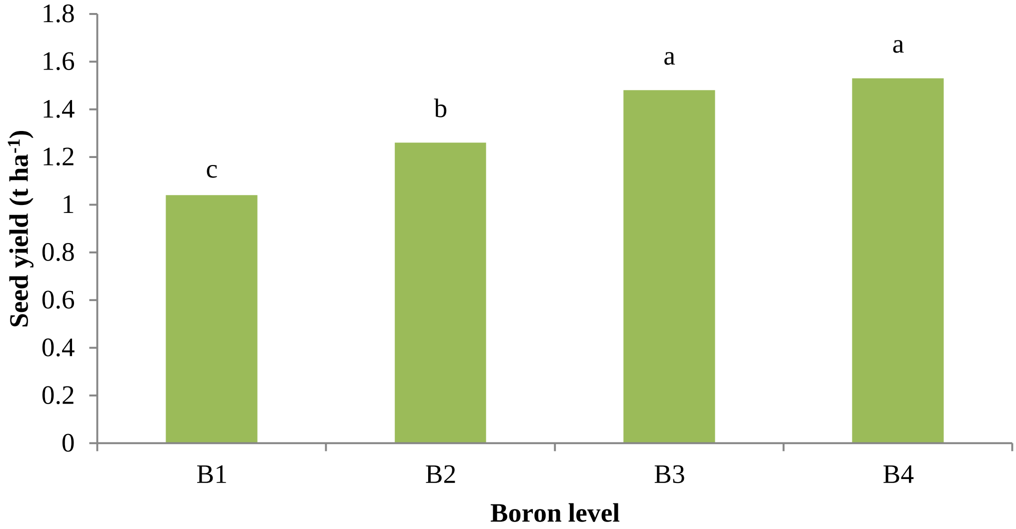
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 19. Effect of zinc on seed yield $hectare^{-1}$ of groundnut ($LSD_{0.05}$= 0.08).

4.10.2 Effect of foliar application of boron

Foliar application of boron exerted significant variation on seed yield (t ha^{-1}) of groundnut under this experiment (Figure 20). The result showed that the maximum seed yield of groundnut was obtained from B_4 (1.53 t ha^{-1}) treatment which was statistically similar to B_3 treatment. On the other hand, the minimum seed yield of groundnut was obtained from B_1 (1.04 t ha^{-1}) treatment. The finding of the experiment was coincided with the findings of Mekdad (2019) who reported that among the three foliar spray with boron levels (B_0: tap water, B_1: 100 ppm and B_2: 150 ppm) on peanut the experimental results indicated that yield components, yield and its quality of peanut were positively ($P \leq 0.01$) affected by foliar application of boron (B_2). Kabir *et al.* (2013) also reported that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 20. Effect of foliar application of boron on seed yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.07).

4.10.3 Combined effect of zinc and foliar application of boron

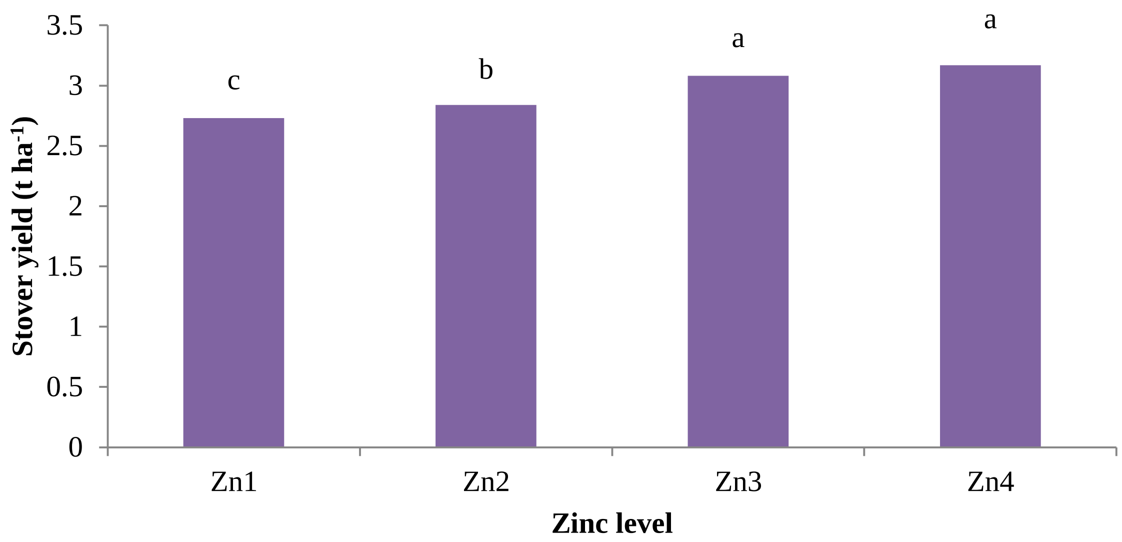
Combined effect of zinc and foliar application of boron exerted significant influence on seed yield of groundnut under the present study (Table 5 Appendix IX). Experimental data revealed that the maximum seed yield of groundnut (1.78 t ha^{-1}) was obtained from Zn_4B_4 treatment combination which was statistically as par with Zn_4B_3 (1.72 t ha^{-1}) and Zn_3B_4 (1.67 t ha^{-1}) treatment combination. On the other hand, the minimum seed yield of groundnut (0.90 t ha^{-1}) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 (0.96 t ha^{-1}) and Zn_2B_1 (1.00 t ha^{-1}) treatment combination.

4.11 Stover yield

4.11.1 Effect of zinc

Significant variation was revealed on stover yield of groundnut due to the effect of different zinc levels (Figure 21). Experimental data revealed that the maximum stover yield (3.17 t ha^{-1}) was obtained from Zn_4 treatment which was statistically similar with Zn_3 treatment while the minimum stover yield (2.73 t ha^{-1}) was obtained from

Zn_1 treatment. Similar trends also observed by El-Habbasha *et al.* (2013) who reported that increasing the use of Zn foliar application either at flowering or seed filling stages significantly increased number of pods plant^{-1}, weight of pods plant^{-1}, number of seeds plant^{-1}, weight of seeds plant^{-1}, 100-pod weight compared to control treatment. Sabra *et al.* (2019) reported that mixture of (Zn + Mn + B) recorded high value comparing with dual effect of (Zn + Mn, Zn + B and Mn + B) also single effect (Zn, Mn and B) for yield components.



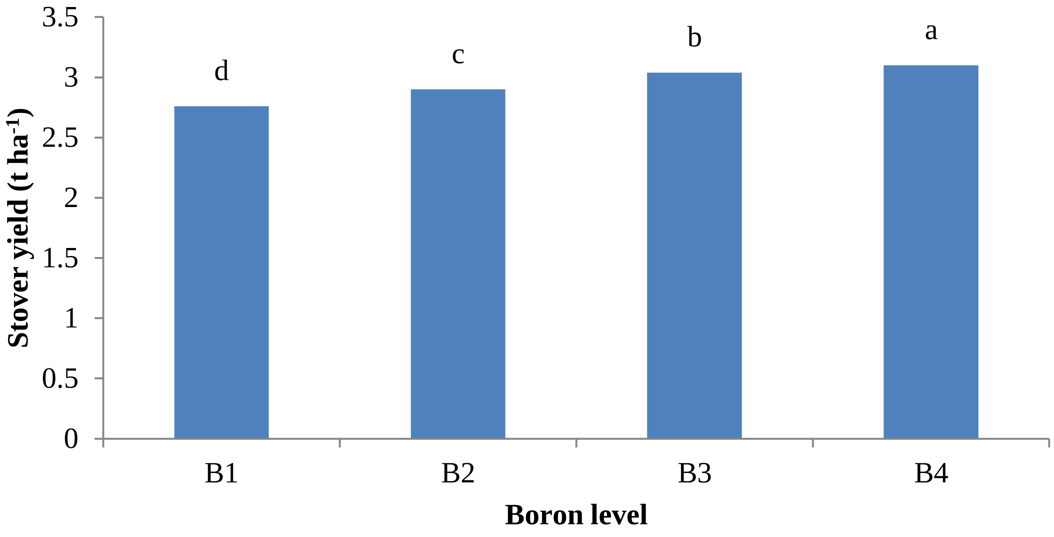
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 21. Effect of zinc on stover yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.09).

4.11.2 Effect of foliar application of boron

Significant variation was observed on stover yield (t ha^{-1}) of groundnut due to the foliar application of boron under this experiment (Figure 22). Experimental data showed that the maximum stover yield of groundnut (3.10 t ha^{-1}) was obtained from B_4 treatment. On the other hand, the minimum stover yield of groundnut was obtained from B_1 (2.76 t ha^{-1}) treatment. The finding of the experiment was coincided with the findings of Kabir *et al.* (2013) who reported that fertilizer doses of B 2.5 kg ha^{-1} increases pod yield, biological yield, straw yield and harvest index.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 22. Effect of foliar application of boron on stover yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.05).

4.11.3 Combined effect of zinc and foliar application of boron

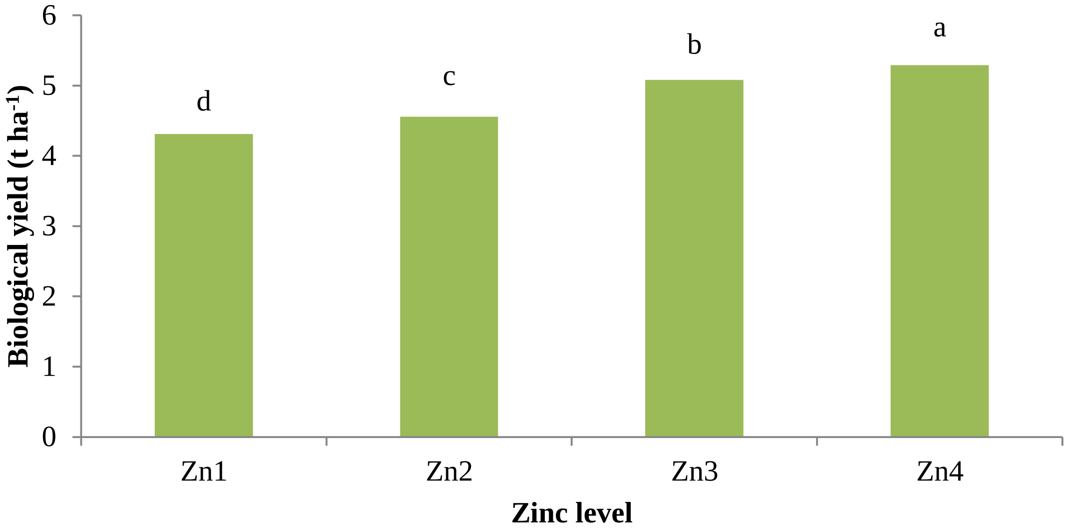
Combined effect of zinc and foliar application of boron showed significant variation on stover yield of groundnut under the present study (Table 5 and Appendix IX). Experimental data revealed that the maximum stover yield (3.36 t ha^{-1}) was obtained from Zn_4B_4 treatment combination which was statistically as par with Zn_4B_3 (3.30 t ha^{-1}) and Zn_4B_3 (3.25 t ha^{-1}) treatment combination. On the other hand, the minimum pod yield of groundnut (2.61 t ha^{-1}) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 and Zn_2B_1 treatment combinations.

4.12 Biological yield

4.12.1 Effect of zinc

Groundnut exerted significant influence on biological yield due to effect of different zinc levels (Figure 23). The result revealed that the maximum biological yield of groundnut (5.29 t ha^{-1}) was obtained from Zn_4 treatment. On the other hand, the minimum biological yield of groundnut (4.31 t ha^{-1}) was achieved from Zn_1 treatment. The result of the experiment was in coincided with the findings of Sabra *et al.* (2019) who reported that Giza 6 variety responded positively to treatments with Zn 400 ppm

+ Mn 400 ppm + B 0.06 as boric acid for pod, seed, straw, biological, oil and protein yield fed^{-1}. Sharma *et al.* (2013) also reported that pod yield, haulm yield, biological yield, harvest index, number of nodules, shelling percentage and seed index etc. significantly increased with the application of Zn upto 5 kg ha^{-1}.



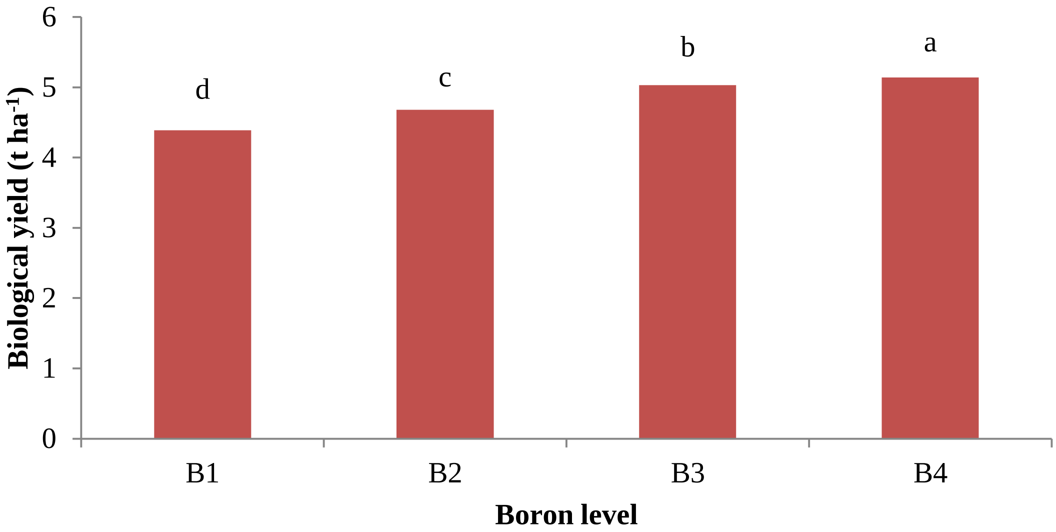
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 23. Effect of zinc on biological yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.12).

4.12.2 Effect of foliar application of boron

Significant effect on biological yield of groundnut was observed due to different foliar application of boron under the present study (Figure 24). Experimental data revealed that the maximum biological yield of groundnut was observed in B_4 (5.14 t ha^{-1}) treatment. On the other hand, the minimum biological yield of groundnut was obtained from B_1 (4.39 t ha^{-1}) treatment. Similar result also found by Kabir *et al.* (2013) who reported that the combined dose of fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 24. Effect of foliar application of boron on biological yield hectare^{-1} of groundnut ($LSD_{0.05}$= 0.09).

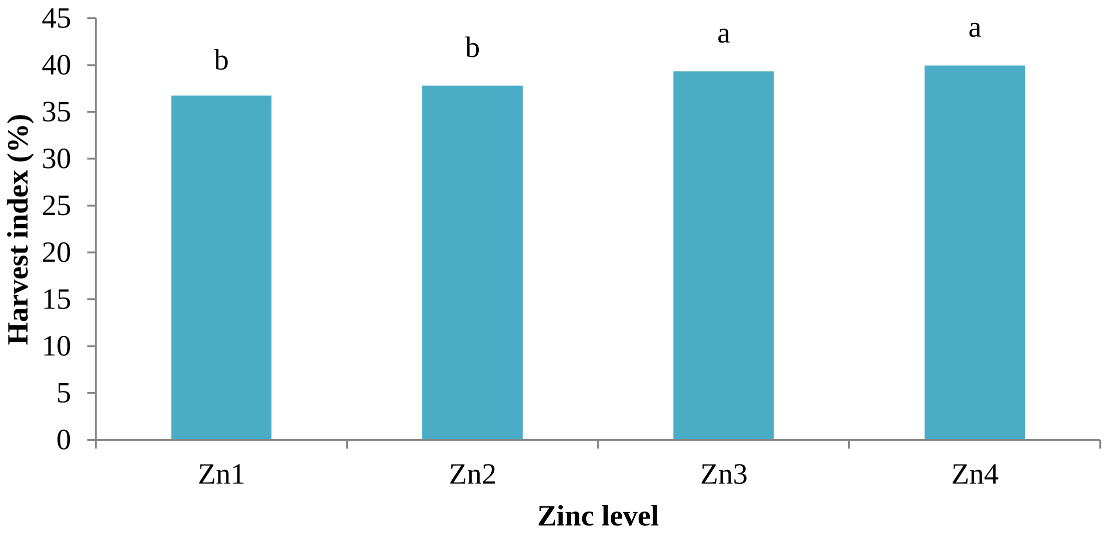
4.12.3 Combined effect of zinc and foliar application of boron

Combined effect of zinc and foliar application of boron showed significant difference on biological yield (t ha^{-1}) of groundnut under the study (Table 5 and Appendix IX). Result revealed that the maximum biological yield of groundnut (5.70 t ha^{-1}) was achieved from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 (5.58 t ha^{-1}) treatment combination. On the other hand, the minimum biological yield of groundnut (4.04 t ha^{-1}) was observed in Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 and Zn_2B_1 treatment combinations.

4.13 Harvest index

4.13.1 Effect of zinc

Harvest index (%) of groundnut showed significant influences due to effect of different zinc levels (Figure 25). Experimental data observed that the maximum harvest index (39.97%) was obtained from Zn_4 treatment. On the other hand, the minimum harvest index (36.75%) was observed in Zn_1 treatment. Similar result was also observed by Sabra *et al.* (2019) who reported that mixture of (Zn + Mn + B) recorded high value comparing with dual effect of (Zn + Mn, Zn + B and Mn + B) also single effect (Zn, Mn and B) for yield components. Influence of interaction revealed that Giza 6 variety recorded high performance for all yield characters except harvest index and oil %. Therefore, Giza 6 variety responded positively to treatments with Zn 400 ppm + Mn 400 ppm + B 0.06 as boric acid for pod, seed, straw, biological, oil and protein yield fed^{-1}. Sharma *et al.* (2013) also revealed that pods per plant, kernels per pod, pod yield, haulm yield, biological yield, harvest index, number of nodules, shelling percentage and seed index etc. significantly increased with the application of Zn upto 5 kg ha^{-1}.

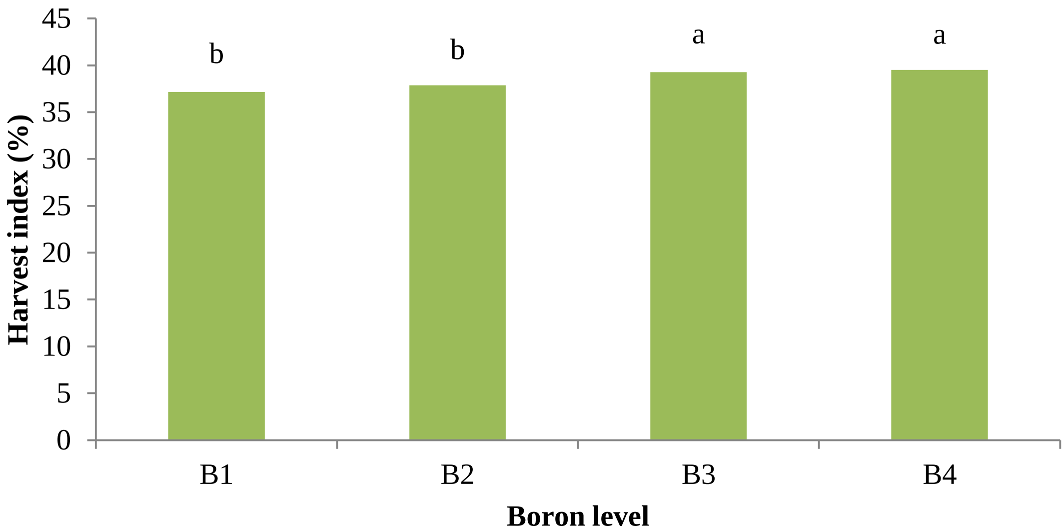


The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability
Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 25. Effect of zinc on harvest index of groundnut ($LSD_{0.05}$= 1.09).

4.13.2 Effect of foliar application of boron

Significant effect on harvest index (%) of groundnut was observed due to foliar application of boron under the study (Figure 26). Experimental data showed that the maximum harvest index of groundnut was obtained from B_4 (39.53%) treatment which was statistically similar with B_3 (39.28%) treatment. On the other hand, the minimum harvest index of groundnut was obtained from B_1 (37.17%) treatment. Similar result was also found by Kabir *et al.* (2013) who reported that the combined dose of P_2, Ca_1 and B_2 produced the highest values for almost all the growth, yield (pod yield, straw yield, biological yield and harvest index) and yield contributing parameters. Thus, it can be concluded that the fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1}, respectively for obtaining the highest yield of groundnut under this particular soil.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 26. Effect of foliar application of boron on harvest index of groundnut ($LSD_{0.05}$= 0.75).

4.13.3 Combined effect of zinc and foliar application of boron

Different zinc levels along with different foliar application of boron remarked significant difference on harvest index (%) of groundnut (Table 5 and Appendix IX). Result revealed that the maximum harvest index of groundnut (41.05%) was obtained from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 (40.86%) treatment combination. On the other hand, the minimum harvest index of groundnut (35.39%) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 (35.97%) treatment combination.

Table 5. Combined effect of zinc and foliar application of boron on pod yield, seed yield, stover yield, biological yield and harvest index of groundnut

Treatment Combinations	Pod yield (t ha^{-1})	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Zn_1B_1	1.43 l	0.90 l	2.61 k	4.04 k	35.39 k
Zn_1B_2	1.50 kl	0.96 kl	2.67 jk	4.17 k	35.97 jk
Zn_1B_3	1.69 hi	1.22 ghi	2.80 ghi	4.49 hi	37.63 h
Zn_1B_4	1.73 gh	1.28 fgh	2.82 gh	4.55 ghi	38.02 gh
Zn_2B_1	1.55 jk	1.00 kl	2.69 ijk	4.24 jk	36.55 ij
Zn_2B_2	1.62 ij	1.06 jk	2.77 hij	4.39 ij	36.90 i
Zn_2B_3	1.84 ef	1.34 efg	2.91 efg	4.75 fg	38.74 def
Zn_2B_4	1.90 de	1.40 ef	2.97 ef	4.87 ef	39.01 cde
Zn_3B_1	1.77 fgh	1.10 ijk	2.85 f-h	4.62 gh	38.31 fg
Zn_3B_2	1.95 d	1.48 de	3.03 de	4.98 e	39.16 cd
Zn_3B_3	2.11 bc	1.62 bc	3.18 bc	5.29 cd	39.88 b
Zn_3B_4	2.17 b	1.67 abc	3.25 abc	5.42 bc	40.03 b
Zn_4B_1	1.80 fg	1.16 hij	2.88 fgh	4.68 fgh	38.46 efg
Zn_4B_2	2.05 c	1.55 cd	3.14 cd	5.19 d	39.49 bc
Zn_4B_3	2.28 a	1.72 ab	3.30 ab	5.58 ab	40.86 a
Zn_4B_4	2.34 a	1.78 a	3.36 a	5.70 a	41.05 a
$LSD_{(0.05)}$	**0.09**	**0.13**	**0.10**	**0.19**	**0.60**
CV(%)	**3.01**	**6.02**	**2.35**	**2.09**	**2.93**

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

Notes *viz:*

Zn_1= 0 kg zinc sulphate ha^{-1}

Zn_2= 2.50 kg zinc sulphate ha^{-1}

Zn_3= 5.00 kg zinc sulphate ha^{-1}

Zn_4= 7.50 kg zinc sulphate ha^{-1}

B_1= control (no boric acid L^{-1} of water)

B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1})

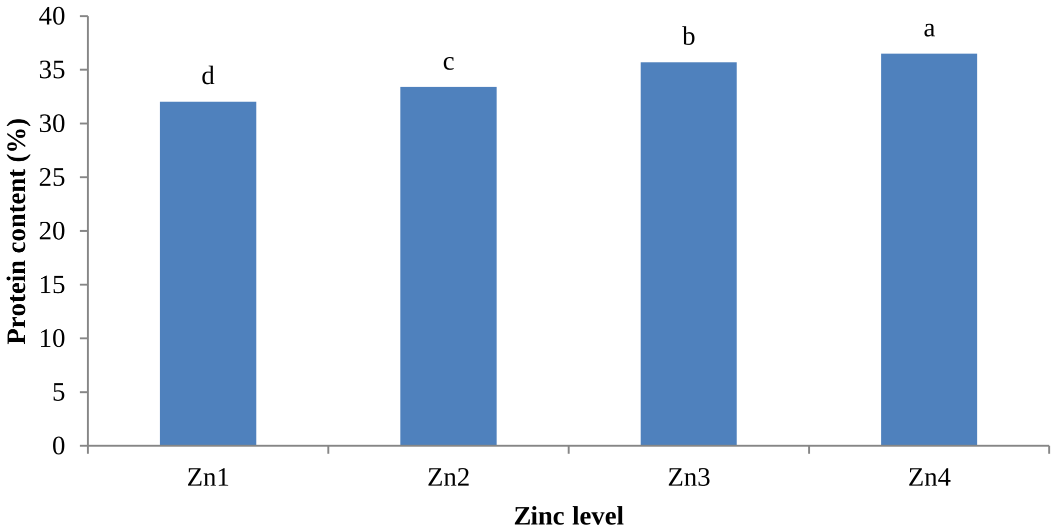
B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1})

B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

4.14 Protein content

4.14.1 Effect of zinc

Protein content (%) of groundnut showed significant influences due to effect of different zinc levels (Figure 27). The experimental data noted that the maximum protein content (36.49%) was obtained from Zn_4 treatment. On the other hand, the minimum protein content (32.04%) was observed in Zn_1 treatment. Similar result was also observed by Saha *et al.* (2015) who reported that application of S and Zn significantly increased the oil content, while it significantly decreased the iodine value in groundnut. So, application of micronutrients *viz.*, Zn and B as well as S fertilization could be a useful strategy not only to increase the yield but also the quality of groundnut.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

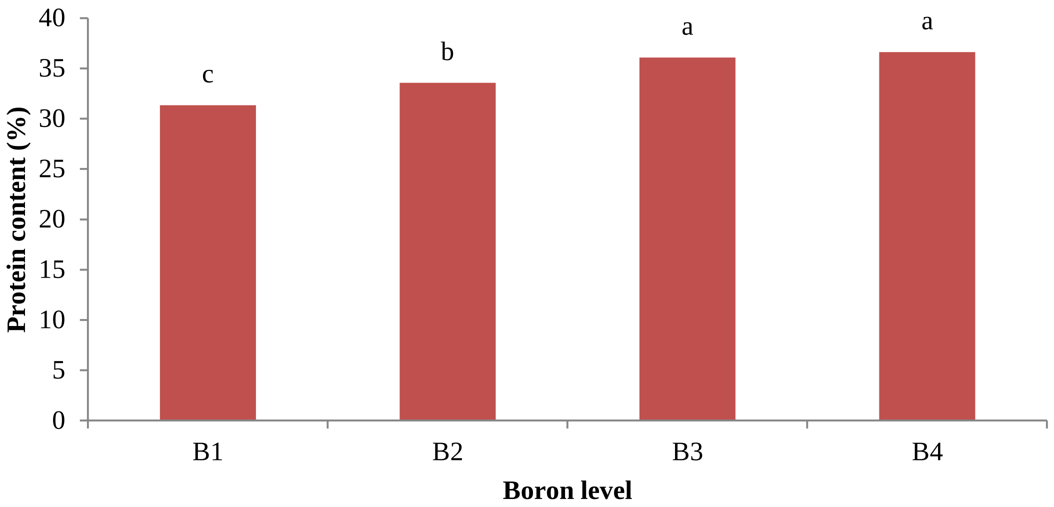
Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 27. Effect of zinc on protein content of groundnut ($LSD_{0.05}$= 0.49).

4.14.2 Effect of foliar application of boron

Significant effect on protein content (%) of groundnut was observed due to foliar application of boron under the study (Figure 28). Experimental data showed that the maximum protein content of groundnut was obtained from B_4 (36.62%) treatment which was statistically similar with B_3 (36.08%) treatment. On the other hand, the minimum protein content of groundnut was obtained from B_1 (31.34%) treatment.

Similar result was also found by Kushwaha *et al*. (2009) who reported that increasing levels of boron application significantly improved the protein content. Nadaf and Chidanandappa (2015) revealed 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.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 28. Effect of foliar application of boron on protein content of groundnut ($LSD_{0.05}$= 0.67).

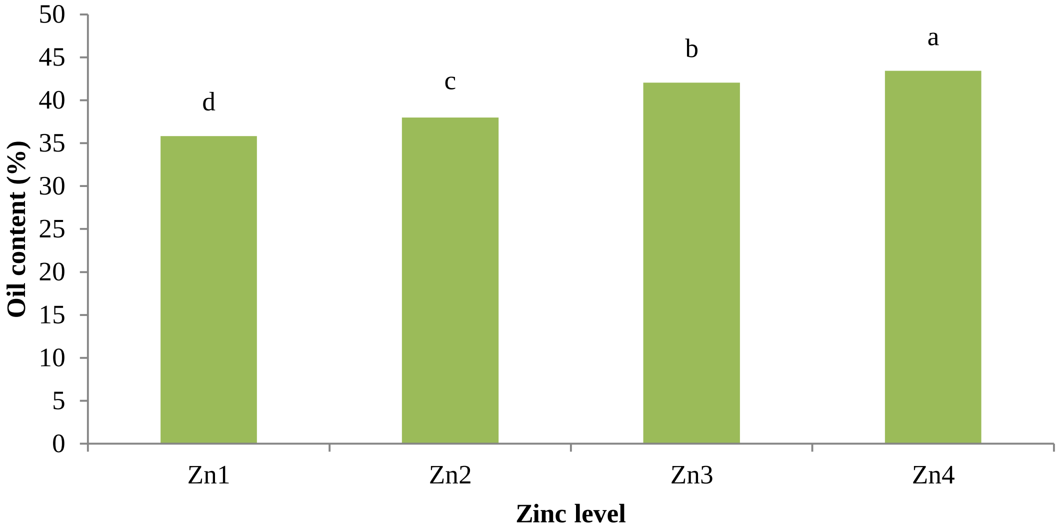
4.14.3 Combined effect of zinc and foliar application of boron

Different zinc levels along with different foliar application of boron marked significant difference on protein content (%) of groundnut (Table 6 and Appendix X). Result revealed that the maximum protein content of groundnut (38.60%) was obtained from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 and Zn_3B_4 treatment combinations. On the other hand, the minimum protein content of groundnut (29.35%) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 treatment combination.

4.15 Oil content

4.15.1 Effect of zinc

Significant variation on oil content (%) of groundnut was observed due to the effect of different zinc levels under the present study (Figure 29). Experimental data noted that the maximum oil content (43.44%) was obtained from Zn_4 treatment. On the other hand, the minimum oil content (35.84%) was observed in Zn_1 treatment. Similar result was also observed by Saha *et al.* (2015) who reported that integrated mode of application of Zn, B and S showed a positive interaction as yield increase with their uptake in groundnut. Oil content in nuts ranged from 45.3 to 54.4%, while iodine value ranged from 97.8 to 90.5%. Application of S and Zn significantly increased the oil content, while it significantly decreased the iodine value in groundnut. So, application of micronutrients *viz.*, Zn and B as well as S fertilization could be a useful strategy not only to increase the yield but also the quality of groundnut.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

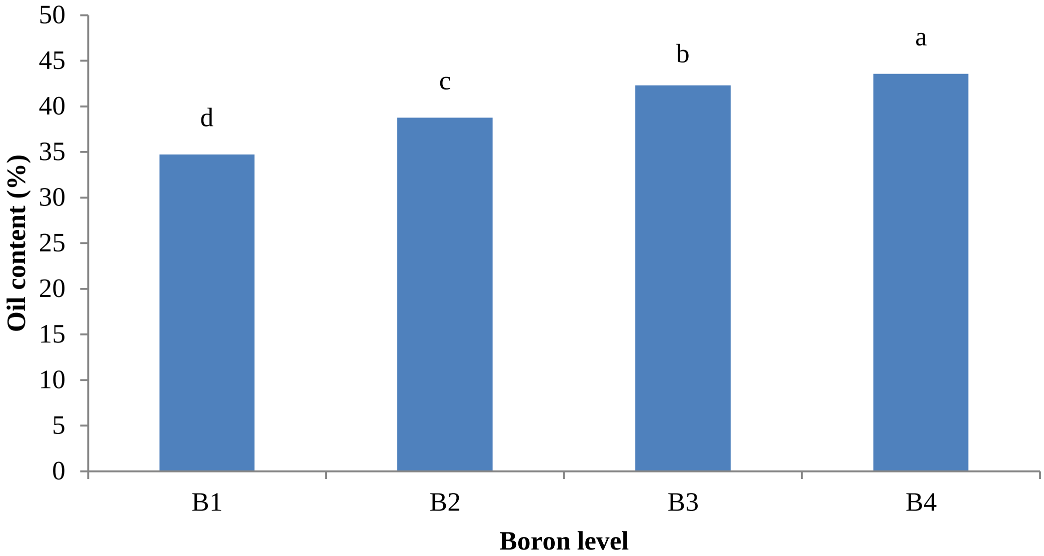
Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 29. Effect of zinc on oil content of groundnut ($LSD_{0.05}$= 1.22).

4.15.2 Effect of foliar application of boron

Significant effect on oil content (%) of groundnut was observed due to foliar application of boron under the study (Figure 30). Experimental data showed that the maximum oil content of groundnut was obtained from B_4 (43.57%) treatment. On the other hand, the minimum oil content of groundnut was obtained from B_1 (34.71%)

treatment. Similar result was also found by Nadaf and Chidanandappa (2015) who revealed 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.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 30. Effect of foliar application of boron on oil content of groundnut ($LSD_{0.05}$= 1.19).

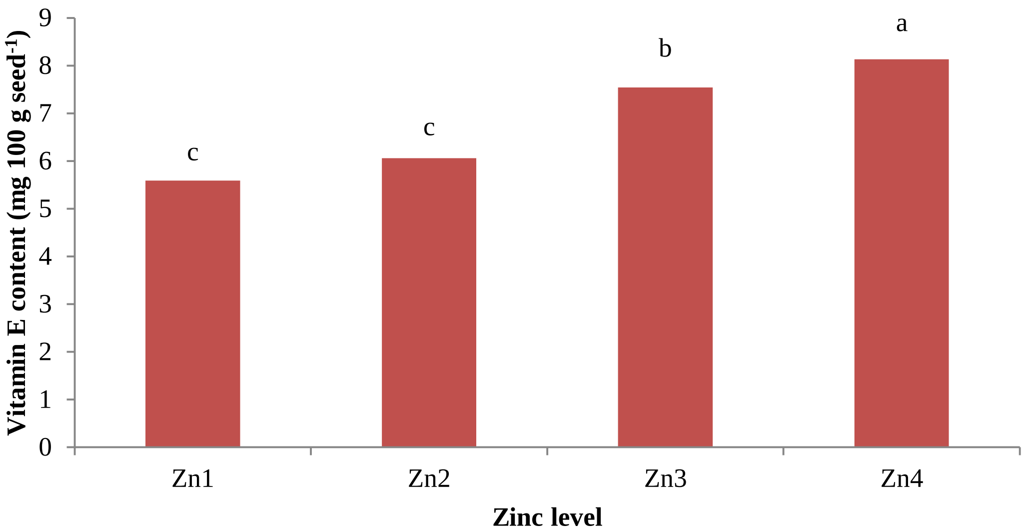
4.15.3 Combined effect of zinc and foliar application of boron

Different zinc levels along with different foliar application of boron remarked significant difference on oil content (%) of groundnut (Table 6 and Appendix X). Result revealed that the maximum oil content of groundnut (47.85%) was obtained from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 treatment combinations. On the other hand, the minimum oil content of groundnut (32.64%) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 and Zn_2B_1 treatment combinations.

4.16 Vitamin E content

4.16.1 Effect of zinc

Vitamin E content (mg 100 g seed^{-1}) of groundnut showed significant influences due to effect of different zinc levels (Figure 31). Experimental data noted that the maximum vitamin E content (8.13 mg 100 g seed^{-1}) was obtained from Zn_4 treatment. On the other hand, the minimum vitamin E content (5.59 mg 100 g seed^{-1}) was observed in Zn_1 treatment which was statistically similar with Zn_2 treatment. Similar result was also observed by Gobarah *et al.* (2006) who reported that foliar spraying with zinc levels had a significant effect on groundnut growth, yield and its components as well as seed quality. It was observed that the most of the characters under study increased significantly by the interaction between phosphorus fertilizer and foliar spraying with zinc expect dry weight of stem, P and oil percentages.



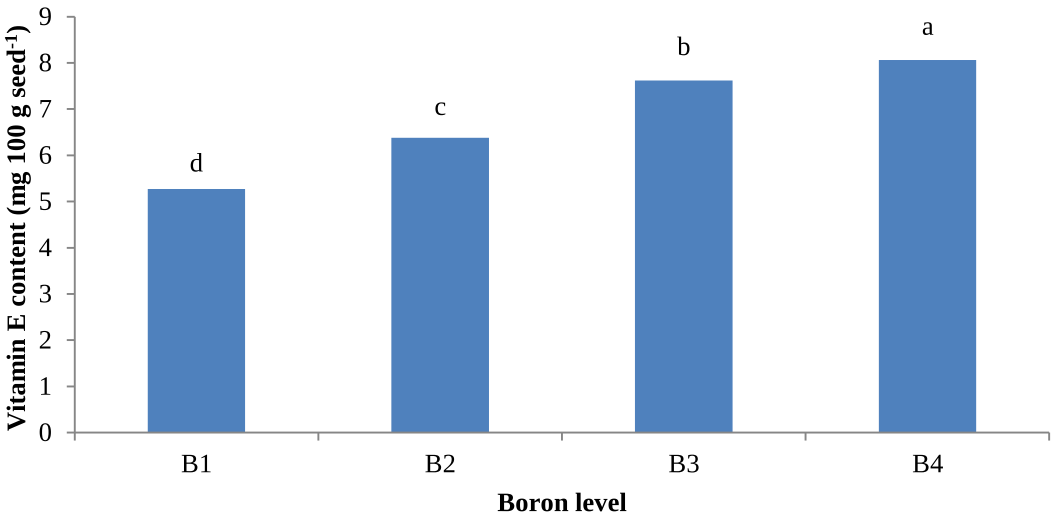
The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 31. Effect of zinc on vitamin E content of groundnut ($LSD_{0.05}$= 0.50).

4.16.2 Effect of foliar application of boron

Significant effect on vitamin E content (mg 100 g seed^{-1}) of groundnut was observed due to foliar application of boron under the study (Figure 32). Experimental data showed that the maximum vitamin E content of groundnut was obtained from B_4 (8.06 mg 100 g seed^{-1}) treatment. On the other hand, the minimum vitamin E content of groundnut was obtained from B_1 (5.27 mg 100^{-1} g seed) treatment. Similar result was also found by Hirpara *et al.* (2019) who reported 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.)



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 32. Effect of foliar application of boron on vitamin E content of groundnut ($LSD_{0.05}$= 0.36).

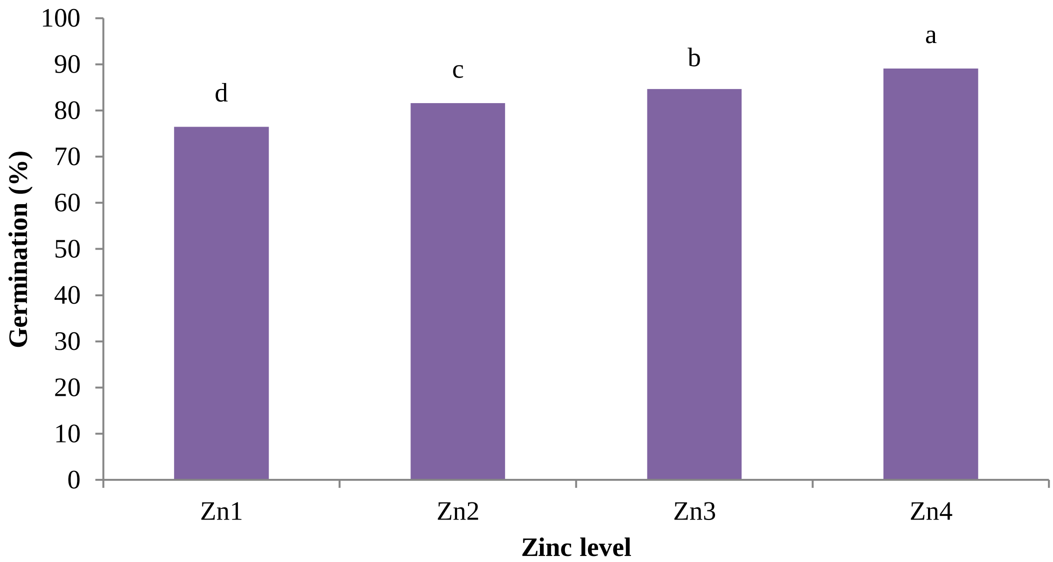
4.16.3 Combined effect of zinc and foliar application of boron

Different zinc levels along with different foliar application of boron remarked significant difference on vitamin E content (mg 100 g $seed^{-1}$) of groundnut (Table 6 and Appendix X). Result revealed that the maximum vitamin E content of groundnut (9.65 mg 100 g $seed^{-1}$) was obtained from Zn_4B_4 treatment combination which was statistically similar with Zn_4B_3 and Zn_3B_4 treatment combinations. On the other hand, the minimum vitamin E content of groundnut (4.75 mg 100 g $seed^{-1}$) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2, Zn_2B_1, Zn_2B_2 and Zn_3B_1 treatment combinations.

4.17 Germination percentage

4.17.1 Effect of zinc

Significant variation on germination (%) of groundnut was observed due to effect of different zinc levels under the present study (Figure 33). Experimental data noted that the maximum germination of groundnut (89.08%) was obtained from Zn_4 treatment. On the other hand, the minimum germination of groundnut (76.43%) was observed in Zn_1 treatment. Similar result was also observed by Sharma *et al.* (2013) who reported that germination percentage and seed quality etc. significantly increased with the application of Zn upto 5 kg ha^{-1}.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

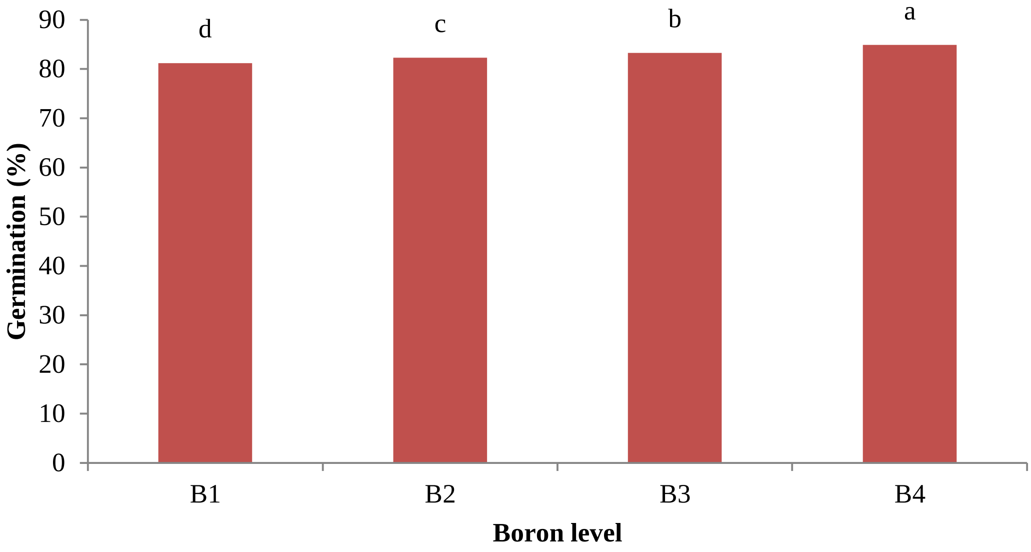
Zn_1= 0 kg zinc sulphate ha^{-1}, Zn_2= 2.5 kg zinc sulphate ha^{-1}, Zn_3= 5 kg zinc sulphate ha^{-1} and Zn_4= 7.5 kg zinc sulphate ha^{-1}

Figure 33. Effect of zinc on germination percentage of groundnut ($LSD_{0.05}$= 1.90).

4.17.2 Effect of foliar application of boron

Significant effect on germination of groundnut (%) of groundnut was observed due to foliar application of boron under the study (Figure 34). Experimental data showed that the maximum germination of groundnut was obtained from B_4 (84.93%) treatment. On the other hand, the minimum germination of groundnut was obtained from B_1 (81.22%) treatment. Similar result was also found by Quamruzzaman *et al.* (2016)

who reported vegetative growth, pods dry weight plant^{-1}, pod yield and germination were markedly increased with the application of boron.



The similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

B_1= control (no boric acid L^{-1} of water), B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

Figure 34. Effect of foliar application of boron on germination percentage of groundnut ($LSD_{0.05}$= 0.72).

4.17.3 Combined effect of zinc and foliar application of boron

Different zinc levels along with different foliar application of boron remarked significant difference on germination (%) of groundnut under the study (Table 6 and Appendix X). Result revealed that the maximum germination of groundnut (91.60%) was obtained from Zn_4B_4 treatment combination where the minimum germination of groundnut (73.90%) was obtained from Zn_1B_1 treatment combination which was statistically similar with Zn_1B_2 treatment combinations.

Table 6. Combined effect of zinc and foliar application of boron on protein content, oil content, vitamin E content and germination percentage of groundnut

Treatment Combinations	Protein content (%)	Oil content (%)	Vitamin E content (mg 100 g seed^{-1})	Germination (%)
Zn_1B_1	29.35 l	32.64 j	4.75 i	73.90 j
Zn_1B_2	30.17 kl	33.80 ij	4.83 i	75.20 j
Zn_1B_3	33.87 gh	37.32 gh	6.17 fg	77.00 i
Zn_1B_4	34.75 fg	39.62 fg	6.62 ef	79.60 h
Zn_2B_1	31.00 jk	34.57 ij	5.05 hi	80.40 h
Zn_2B_2	31.74 ij	35.18 hi	5.25 hi	81.30 gh
Zn_2B_3	35.28 ef	40.81 ef	6.83 ef	81.90 g
Zn_2B_4	35.52 ef	41.45 ef	7.10 e	82.70 fg
Zn_3B_1	32.23 ij	35.52 hi	5.53 ghi	83.50 fg
Zn_3B_2	35.92 def	42.87 de	7.42 de	84.30 ef
Zn_3B_3	37.05 bcd	44.46 bcd	8.35 bc	85.00 de
Zn_3B_4	37.62 abc	45.37 bc	8.85 ab	85.80 d
Zn_4B_1	32.77 hi	36.13 hi	5.75 gh	87.10 cd
Zn_4B_2	36.42 cde	43.17 cde	8.00 cd	88.40 bc
Zn_4B_3	38.15 ab	46.62 ab	9.12 ab	89.20 b
Zn_4B_4	38.60 a	47.85 a	9.65 a	91.60 a
$LSD_{(0.05)}$	**1.34**	**2.38**	**0.72**	**1.43**
CV(%)	**2.32**	**3.55**	**6.31**	**1.04**

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

Notes *viz:*

Zn_1= 0 kg zinc sulphate ha^{-1}
Zn_2= 2.50 kg zinc sulphate ha^{-1}
Zn_3= 5.00 kg zinc sulphate ha^{-1}
Zn_4= 7.50 kg zinc sulphate ha^{-1}

B_1= control (no boric acid L^{-1} of water)
B_2= 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1})
B_3= 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1})
B_4= 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1})

CHAPTER V

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was carried out at the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during April 2021 to August 2021 to study the effect of zinc and boron fertilizer on yield and seed quality of groundnut. The experiment consisted of two factors. Factor A: Zinc fertilizer (4 levels) *viz.*, Zn_1: 0 kg zinc sulphate ha^{-1} (control), Zn_2: 2.50 kg zinc sulphate ha^{-1}, Zn_3: 5.00 kg zinc sulphate ha^{-1} and Zn_4: 7.50 kg zinc sulphate ha^{-1}, and factor B: Foliar application of boron (4 levels) *viz.*, B_1: Control (no boric acid L^{-1} of water), B_2: 0.75 g boric acid L^{-1} of water (3.75 kg boric acid ha^{-1}), B_3: 1.00 g boric acid L^{-1} of water (5.00 kg boric acid ha^{-1}) and B_4: 1.25 g boric acid L^{-1} of water (6.25 kg boric acid ha^{-1}). The experiment was laid out in a Split-plot design with three replications. There were 16 treatment combinations. The total numbers of unit plots were 48. The size of unit plot was 4.00 m^2 (2.00 m × 2.00 m). Zinc fertilizer was placed along the main plot and foliar application of boron was placed along the sub plot. The data on different growth, yield contributing parameters, yield and seed quality of groundnut were recorded and statistically analyzed.

Different growth and yield contributing parameters were significantly influenced by different zinc levels. Results revealed that the longest plant (15.24, 21.87, 32.42, 42.21 and 45.28 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves $plant^{-1}$ (14.99, 30.58, 38.21, 42.83 and 40.04 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches $plant^{-1}$ (3.41, 6.23, 7.50, 8.08 and 8.58 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_4 treatment. The maximum number of pods $plant^{-1}$ (22.16), pod length (2.59 cm), 100 seeds weight (44.45 g), pod yield $plot^{-1}$ (847.00 g), seed yield $plot^{-1}$ (621.00 g), pod yield (2.12 t ha^{-1}), seed yield (1.55 t ha^{-1}), stover yield (3.17 t ha^{-1}), biological yield (5.29 t ha^{-1}) and harvest index (40.97%) were obtained from Zn_4 treatment. The maximum protein content (36.49%), oil content (43.44%), vitamin E content (8.13 mg 100 g $seed^{-1}$) and germination (89.08%) were obtained from Zn_4 treatment. On the other hand,, the shortest plant (12.90, 17.82, 25.42, 32.48 and 36.44 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves $plant^{-1}$ (11.73, 23.49, 27.66, 31.77 and 28.65 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (2.21, 4.93, 6.17, 6.50 and 6.91 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_1 treatment. The minimum number of pods plant^{-1} (18.60), pod length (2.37 cm), 100 seeds weight of groundnut (37.38 g), pod yield plot^{-1} (635.00 g), seed yield plot^{-1} (436.00 g), pod yield (1.59 t ha^{-1}), seed yield (1.09 t ha^{-1}), stover yield (2.73 t ha^{-1}), biological yield (4.31 t ha^{-1}) and harvest index (36.75%) were obtained from Zn_1 treatment. The minimum protein content (32.04%), oil content (35.84%), vitamin E content (5.59 mg 100 g seed^{-1}) and germination (76.43%) were observed in Zn_1 treatment.

Different foliar application of boron showed significant influence on growth, yield contributing parameters, yield and seed quality of groundnut. In case of foliar application of boron, results revealed that the longest plant (14.95, 21.40, 31.40, 41.18 and 44.15 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (14.54, 29.88, 36.84, 41.27 and 38.21 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (3.23, 6.04, 7.42, 7.92 and 8.33 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from B_4 treatment. The maximum number of pods plant^{-1} (22.19), pod length (2.58 cm), 100 seeds weight of groundnut (44.33 g), pod yield plot^{-1} (814.00 g), seed yield plot^{-1} (613.00 g), pod yield (2.04 t ha^{-1}), seed yield (1.53 t ha^{-1}), stover yield (3.10 t ha^{-1}), biological yield (5.14 t ha^{-1}) and harvest index (39.53%) were obtained from B_4 treatment. The maximum protein content (36.62%), oil content (43.57%), vitamin E content (8.06 mg 100 g seed^{-1}) and germination (84.93%) were obtained from B_4 treatment. On the other hand,, the shortest plant (13.10, 18.36, 26.13, 33.62 and 37.56 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (12.23, 24.42, 28.81, 33.35 and 30.50 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (2.37, 5.11 6.34, 6.75 and 7.17 at 25, 50, 75, 100 DAS and at harvest, respectively) were observed in B_1 treatment. The minimum number of pods plant^{-1} (18.18), pod length (2.35 cm), 100 seeds weight (36.56 g), pod yield plot^{-1} (655.00 g), seed yield plot^{-1} (416.00 g), pod yield (1.64 t ha^{-1}), seed yield (1.04 t ha^{-1}), stover yield (2.76 t ha^{-1}), biological yield (4.39 t ha^{-1}) and harvest index (37.17%) were observed in B_1 treatment. The minimum protein content (31.34%), oil content (34.71%), vitamin E content (5.27 mg 100 g seed^{-1}) and germination (81.22%) were observed in B_1 treatment.

Combined effect of zinc and foliar application of boron showed significant influence on growth, yield contributing characters and yield of groundnut. Results revealed that the longest plant (16.67, 23.38, 34.70, 45.20 and 48.41 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (16.00, 32.67, 42.50, 46.33 and 44.67 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (3.83, 6.67, 8.00, 8.67 and 9.33 at 25, 50, 75, 100 DAS and at harvest, respectively) were obtained from Zn_4B_4 treatment combinations. The maximum number of pods plant^{-1} (23.87), pod length (2.70 cm), 100 seeds weight of groundnut (47.83 g), pod yield plot^{-1} (936.00 g), seed yield plot^{-1} (712.00 g), pod yield (2.34 t ha^{-1}), seed yield (1.78 t ha^{-1}), stover yield (3.36 t ha^{-1}), biological yield (5.70 t ha^{-1}) and harvest index (41.05%) were obtained from Zn_4B_4 treatment combinations. The maximum protein content (38.60%), oil content (47.85%), vitamin E content (9.65 mg 100 g seed^{-1}) and germination (91.60%) were obtained from Zn_4B_4 treatment combinations. On the other hand,, the shortest plant (12.45, 16.51, 23.54, 28.92 and 33.75 cm at 25, 50, 75, 100 DAS and at harvest, respectively), number of leaves plant^{-1} (10.75, 20.33, 25.50, 29.75 and 26.33 at 25, 50, 75, 100 DAS and at harvest, respectively), number of branches plant^{-1} (1.93, 4.50, 5.67, 6.00 and 6.33 at 25, 50, 75, 100 DAS and at harvest, respectively) were observed from Zn_1B_1 treatment combinations. On the other hand, the minimum number of pods plant^{-1} (16.76), pod length (2.27 cm), 100 seeds weight (34.18 g), pod yield plot^{-1} (572.00 g), seed yield plot^{-1} (360.00 g), pod yield (1.43 t ha^{-1}), seed yield (0.90 t ha^{-1}), stover yield (2.61 t ha^{-1}), biological yield (4.04 t ha^{-1}) and harvest index (35.39%) were observed from Zn_1B_1 treatment combinations. The minimum protein content (29.35%), oil content (32.64%), vitamin E content (4.75 mg 100 g seed^{-1}) and germination (73.90%) were observed from Zn_1B_1 treatment combinations.

The results in this research showed that the plants performed best in respect of pod yield in Zn_4B_4 (2.34 t ha^{-1}) treatment combination than the combination Zn_1B_1 (1.43 t ha^{-1}) which showed the least performance. In case of seed quality, Zn_4B_4 treatment combination showed the best result than the combination of Zn_1B_1 which showed the least performance. It can be therefore, concluded from the above study that the treatment combination Zn_4B_4 (groundnut growing on 7.50 kg zinc sulphate ha^{-1} with foliar application of boron as boric acid @1.25 g L^{-1} of water) was found to be most suitable combination for the potential pod yield and seed quality of groundnut.

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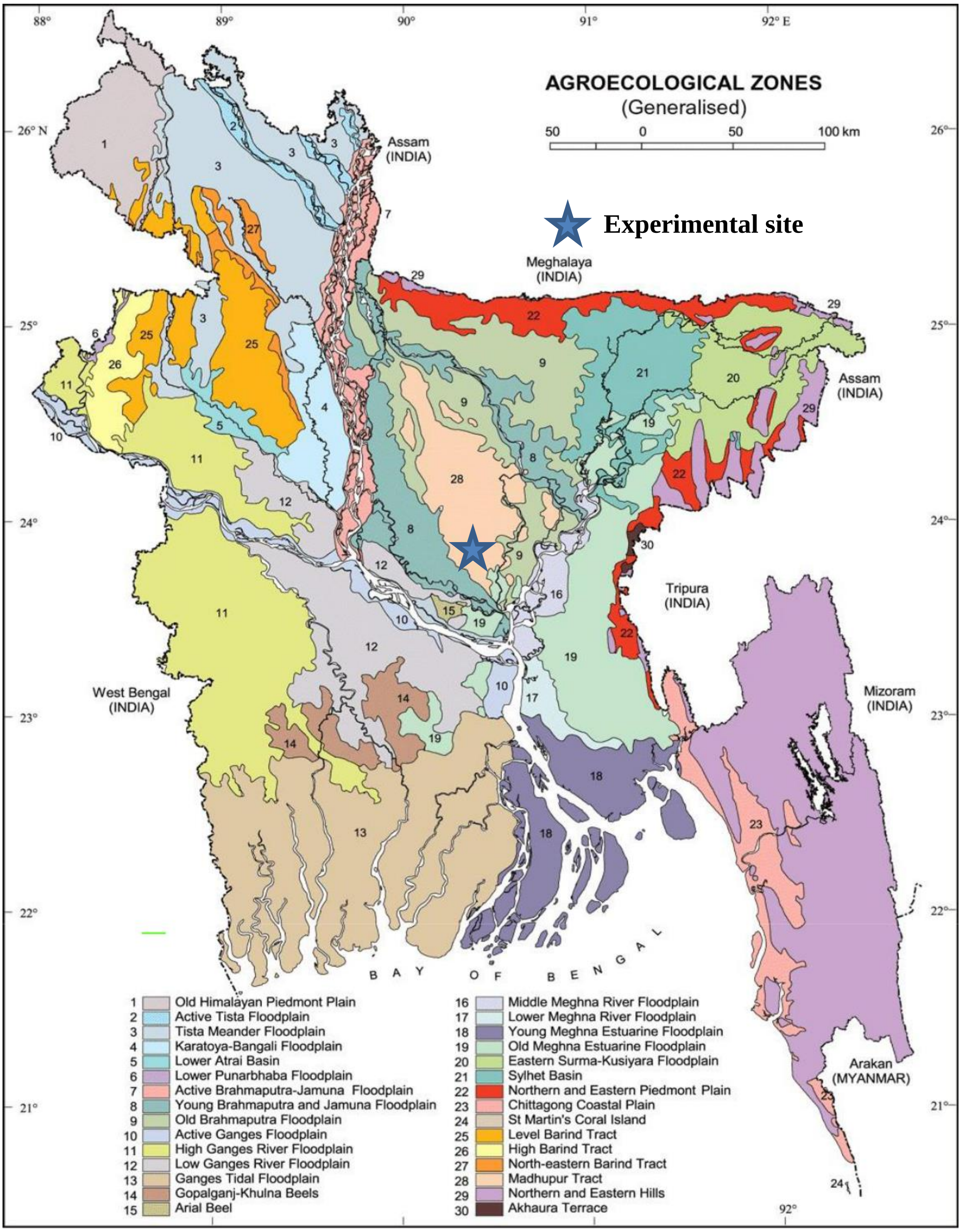
APPENDICES

APPENDICES

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



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

A. Morphological characteristics of the experimental field

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

Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

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

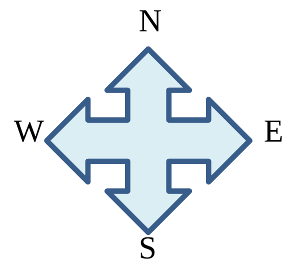
Source: Soil Resource Development Institute (SRDI)

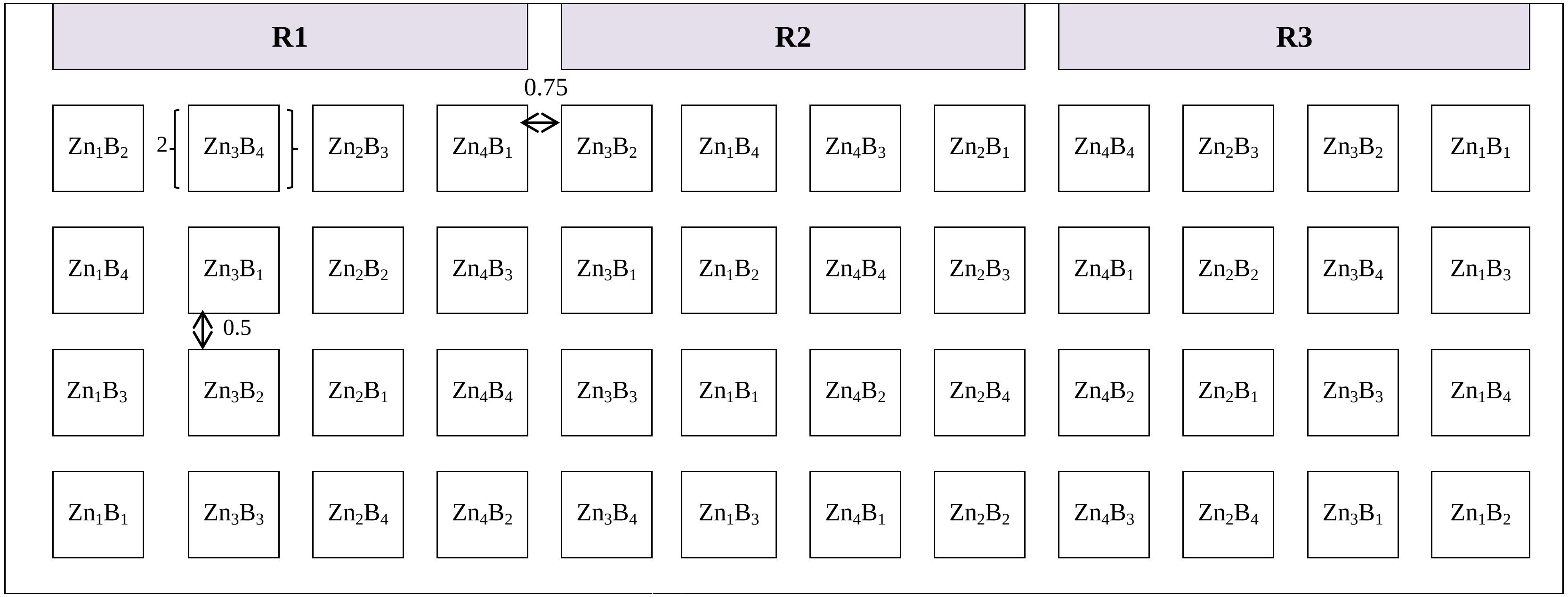
Appendix III. Monthly records of air temperature, relative humidity and total rainfall during the period from April 2021 to August 2021

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

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

Appendix IV. Layout of the experimental plot





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

Replication to replication distance: 0.75 m

Plot to plot distance: 0.5 m,

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

Notes *viz:*

Zn_1= 0 kg zinc sulphate ha^{-1}
Zn_2= 2.50 kg zinc sulphate ha^{-1}
Zn_3= 5.00 kg zinc sulphate ha^{-1}
Zn_4= 7.50 kg zinc sulphate ha^{-1}

B_1= control (no boric acid L^{-1} of water)
B_2= 0.75 g boric acid L^{-1} of water
B_3= 1.00 g boric acid L^{-1} of water
B_4= 1.25 g boric acid L^{-1} of water

Appendix V. Mean square values of plant length at different days after sowing of groundnut growing under the experiment

Sources of variation	Degrees of freedom	Mean square values of plant length at				
		25 DAS	50 DAS	75 DAS	100 DAS	Harvest
Replication	2	3.1329	8.8374	31.6850	66.470	37.700
Factor A	3	13.5177**	41.7446**	124.973**	247.334**	200.017**
Error	6	0.2603	0.3312	0.1440	0.6870	0.8730
Factor B	3	8.1085**	23.5307**	66.3470**	138.919**	106.485**
A × B	9	0.4795**	0.4291*	2.8420**	2.6750*	1.620*
Error	24	0.1016	0.2096	0.6000	1.0160	0.7800

* significant at 5% level of significance

** significant at 1% level of significance

Appendix VI. Mean square values of number of leaves plant^{-1} at different days after sowing of groundnut growing during experimentation

Sources of variation	Degrees of freedom	Mean square values of number of leaves plant^{-1} at				
		25 DAS	50 DAS	75 DAS	100 DAS	Harvest
Replication	2	4.6548	58.1410	65.2060	91.8240	90.250
Factor A	3	26.6813**	129.960**	292.713**	308.691**	310.187**
Error	6	0.1744	2.0570	0.9520	1.6160	0.7500
Factor B	3	13.6782**	76.5770**	157.552**	150.042**	148.023**
A × B	9	0.2798**	2.0280**	7.5010**	8.2410**	5.5920**
Error	24	0.0876	0.4110	0.7820	1.1160	1.1250

* 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 growing during experimentation

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	0.4258	0.8118	0.9801	1.0353	1.1395
Factor A	3	3.6085**	4.2002**	4.2968**	5.9568**	7.0695**
Error	6	0.0429	0.0183	0.0193	0.0696	0.0611
Factor B	3	1.8339**	2.2689**	2.5740**	3.0773**	3.7161**
A × B	9	0.0474**	0.0372*	0.0575*	0.0581*	0.1089*
Error	24	0.0094	0.0136	0.0287	0.0420	0.0425

* 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, pod yield plot^{-1}, weight of 100 seeds and seed yield plot^{-1} of groundnut growing during experimentation

Sources of variation	Degrees of freedom	Mean square values of				
		Number of pods plant^{-1}	Length of pod	Pod yield plot^{-1}	Weight of 100-seed	Seed yield plot^{-1}
Replication	2	46.0702	0.0203	3221.00	110.2500	20592.2
Factor A	3	32.5177**	0.1256**	113731.0**	129.0060**	91448.0**
Error	6	0.2118	0.00051	384.00	1.5830	1531.7
Factor B	3	39.1723**	0.1381**	64587.0**	149.3210**	96424.0**
A × B	9	1.0153*	0.0033*	1214.0**	4.9060**	2981.3*
Error	24	0.3847	0.0012	327.00	1.2500	1034.0

* significant at 5% level of significance

** significant at 1% level of significance

Appendix IX. Mean square values of pod yield, seed yield, stover yield, biological yield and harvest index of groundnut

Sources of variation	Degrees of freedom	Mean square values of				
		Pod yield	Seed yield	Stover yield	Biological yield	Harvest index
Replication	2	0.0400	0.0541	0.1173	0.8836	5.6051
Factor A	3	0.7108**	0.5716**	0.5139**	2.4333**	25.5971**
Error	6	0.0019	0.0075	0.0088	0.0153	1.2076
Factor B	3	0.4037**	0.6027**	0.2852**	1.3656**	15.1558**
A × B	9	0.0076*	0.0186*	0.0090*	0.0319*	0.2465*
Error	24	0.0031	0.0064	0.0038	0.0127	0.8111

* significant at 5% level of significance

** significant at 1% level of significance

Appendix X. Mean square values of protein content, oil content, vitamin E content and germination percentage of groundnut

Sources of variation	Degrees of freedom	Mean square values of			
		Protein content	Oil content	Vitamin E content	Germination percentage
Replication	2	39.5327	8.6360	2.0736	172.3130
Factor A	3	50.6947**	148.8560**	17.2749**	339.4820**
Error	6	0.2493	1.5030	0.2537	3.6460
Factor B	3	71.4698**	189.7460**	19.0456**	29.6120**
A × B	9	1.7162*	7.9500**	0.7947**	1.7140*
Error	24	0.6368	1.9990	0.1858	0.7290

* significant at 5% level of significance

** significant at 1% level of significance