RESPONSE OF ZINC AND BORON ON GROWTH, YIELD AND QUALITY OF BLACK GRAM (*Vigna mungo* L.)

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CERTIFICATE

*This is to certify that the thesis titled, " **Response of Zinc and Boron on growth, yield and quality of Black gram (Vigna mungo L.)"** submitted to the **Dept. of Agronomy, Faculty of Agriculture, Sher–e–Bangla Agricultural University, Sher–e–Bangla Nagar, Dhaka** in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in Agronomy** embodies the result of a piece of bona fide research work carried out by **Abu Sayem Md. Ahsan Habib**; **Registration No. 11-4698** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged by the Author.

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ABSTRACT

The experiment was conducted at the research field of the Department of Agronomy, SAU, Dhaka–1207 during the period from August, 2012 to December, 2012 to study on the performance of black gram as influenced by the various levels of Zinc (Zn) and Boron (B) fertilizers. The black gram variety cv. BARI Mash–3, four levels of Zn (0, 1.25, 2.50 and 3.75 kg ha^{-1}) and five levels of B (0, 0.5, 1.0, 1.5 and 2.0 kg ha^{-1}) as soil application were applied in the study. Besides, a blanket dose of N_{20} P_{150} K_{50} Kg ha^{-1} was used to nourished the plants. The experiment was laid out in two factors split-plot Design with three replications. Result showed that the different levels of Zn and B had significant effect on growth yield and quality parameters of black gram. All the parameters increased with increasing Zn and B levels up to 2.5 kg Zn ha^{-1} and 1.5 kg B ha^{-1} and thereafter decreased the values with increasing Zn and B levels except the pod length. Experimental results revealed that, plant height, leaves $plant^{-1}$, branches $plant^{-1}$, total dry matter, leaf area index, absolute growth rate, relative growth rate and crop growth rate were obtained maximum by the application of 2.50 kg Zn ha^{-1} and 1.50 kg B ha^{-1}, respectively. At harvest yield and yield contributing characters *viz.*, grain yield, 1000- seed weight, straw yield, biological yield and harvest index increased significantly by the application of 2.50 kg Zn ha^{-1} and 1.50 kg B ha^{-1}, respectively. Similar trend was also found in the quality characters such as N, P, K and S content of black gram seed compare with other treatment combinations. Among the all above characters were perform lower in control treatment. These results indicated that the application of 2.5 kg Zn ha^{-1} or 1.5 kg B ha^{-1} would be optimum level for maximizing the seed yield and quality of black gram under the region of AEZ–28.

CONTENTS

CONTENTS (Contd.)

CONTENTS (Contd.)

CONTENTS (Contd.)

LIST OF TABLES

LIST OF TABLES (Contd.)

LIST OF FIGURES

LIST OF FIGURES (Contd.)

LIST OF APPENDICES

ABBREVIATIONS

AEZ	=	Agro–Ecological Zone
Agric.	=	Agriculture
Agril.	=	Agricultural
ANOVA	=	Analysis of variance
B	=	Boron
BARC	=	Bangladesh Agricultural Researcher Council
BARI	=	Bangladesh Agricultural Research Institute
BAU	=	Bangladesh Agricultural University
BBS	=	Bangladesh Bureau of Statistics
CRD	=	Completely randomized design
DAS	=	Days after sowing
EFSB	=	eggplant fruit and shoot borer
FAO	=	Food and Agriculture Organization
LSD	=	Least significant difference
RCBD	=	Randomized Complete Block Design
RDF	=	Recommended dose of fertilizer
Viz.	=	Namely
Zn	=	Zinc

CHAPTER I
INTRODUCTION

Pulses are important crops in Bangladesh. They occupy an area of about 253 thousands hectare with an annual production of 231 thousands metric tons while the average yield was 1000 kg ha^{-1} in 2010–11 (BBS, 2012). Pulses mainly being the Rabi season crop are losing area under cultivation each year for increasing cultivation of wheat, vegetables and high yielding boro rice due to increasing irrigation facilities. Blackgram (*Vigna mungo* L.) is an important pulse crop in Bangladesh. It is locally known as 'Mashkalai'. It occupies an area of 32 thousand hectare producing 29 thousand metric tons, a mean yield of 1000 kg ha^{-1} and contributing about 12.55% of the total pulses (BBS, 2012). Blackgram also ranked third both in area and production among the pulses (BBS, 2012). However, per hectare yield in Bangladesh is low (1000 kg ha^{-1}) compared to the other pulse crops such as Arhar (1350 kg ha^{-1}), Masur (1100 kg ha^{-1}), Mung (1023 kg ha^{-1}) and both Motor and Khesari (1012 kg ha^{-1}) at 2010–11 (BBS, 2012). Black gram cultivation is scattered over the northern districts, especially in Rajshahi and Chapai Nawabganj district. It is relatively a hardier pulse crop. Since it is photo–insensitive legume crop, it can be grown almost throughout the year. But in case of southern districts it is less cultivated due to ignorance and different types of soil and environmental factors.

India is considered as the primary centre of origin and central Asia as the secondary centre of origin of blackgram. The distribution of blackgram is comparatively restricted to the tropical regions. Blackgram is an important grain legume in India, Pakistan, Mayanmar and some parts of South–East Asia, parts of Africa and America. In West Indies, also it is grown mainly as a grain crop. On the other hand, Malnutrition is a serious problem that has been a great threat to cripple the whole nation in Bangladesh. Pulse, a protein rich agricultural crop, plays an important role in human nutrition. It is the cheapest source of protein for the poor and is called the poor men's meat (Mian, 1976). Pulses contain a remarkable amount of proteins, minerals, vitamins and carbohydrates. Among the various pulses, black gram is important one which contains approximately 25–28% protein, 4.5–5.5% ash, 0.5–1.5% oil, 3.5–4.5% fibre and 62.65% carbohydrate on dry weight basis (Kaul, 1982). It contains sulphur, amino acids, methionine and cysteine and also lycine which are excellent components of balanced human nutrition. It has been used as food providing major source of protein in cereal based diet. The dried whole seeds or split are used to make dal, sours, curries and are added to various spiced or fried dishes. Legumes are also good source of calcium, iron, phosphorus, magnesium, sodium, potassium, copper, sulphur and vitamins (Thiamine, riboflavin, nicotinic acid, vitamin C, carotene etc.). The thiamine content in different pulse was found to vary from 3.1 to 5.0 $\mu g\ g^{-1}$. Besides, pulses are capable to fix atmospheric nitrogen to soil and are also used as fodder, green manuring and cover crops. Inspite of its various uses, its cultivation is decreasing day by day both in area and yield (BBS, 2012) which badly affects on human health. A minimum intake of pulse should be 80 g $head^{-1}\ day^{-1}$, whereas, it is only 14.19 g in Bangladesh (BBS, 2009) in case of the fact that national production of the pulses is not adequate to meet the national demand. So, increase of pulse production is urgently needed to meet up the demand of the people, reduce import, save foreign currency and to increase pulse consumption.

Nutrient deficiency in soil is the key factor for poor productivity of pulses. The extent and magnitude of nutrient deficiency has aggravated in the recent past due to intensive agriculture and indiscriminate use of plant nutrients (Anonymous, 2009). The magnitude of yield losses due to nutrient deficiency also varies among the nutrients (Ali *et al*., 2002). Micronutrient availability for the plant depends, among other factors, texture, organic matter and, mainly, soil pH. The soils of different parts of Bangladesh are also more or less deficient in boron which causes poor yield of pulses. Besides, Paul (2009) reported that high cost and environmentally risky chemical fertilizers causes serious and continuous problem for increasing pulse (Black gram) production in developing countries including Bangladesh. These problems are likely to become serious in future. Micronutrients play an important role in increasing yield of pulses and oilseed legumes through their effects on the plant itself and on the nitrogen fixing symbiotic process.

Importance of Zn as a micronutrient in crop production has increased in recent years (Fageria, 2006), hence considered to be the most yield–limiting micronutrient (Duffy, 2007; Fageria and Baligar, 2005). Zinc deficiency decreases crop yield and delays crop maturity. Also, Zinc deficiency reduces water use and water use efficiency (Khan *et al*., 2004) and also reduces nodulation and nitrogen fixation (Ahlawat *et al*., 2007), which contributes to a decrease in crop yield. In neutral to alkaline soils, Zn deficiencies can be encountered (Roy *et al*., 2006), Zn solubility decreases markedly above pH 6.0–6.5 (Sims, 2000). The Zn essentially is being employed in functional and structural component of several enzymes, such as carbonic anhydrase, alcohol dehydrase, alkaline phosphatase, phospholipase, carboxypeptidase (Coleman, 1991) and RNA polymerase (Romheld and Marschner, 1991). Further, plants emerging from seeds with lower Zn could be highly sensitive to biotic and abiotic stresses (Obata *et al*., 1999). Zinc enriched seeds performs better with respect to seed germination, seedling growth and yield of crops (Cakmak *et al*., 1996).

Boron (B), essential element for all vascular plants, whose deficiency or excess causes impairments in several metabolic and physiological processes (Camacho–Cristobal *et al*., 2008; Reid, 2007) including cell wall structure, function and in pod and seed formation (O'Neill *et al*., 2004). Valenciano *et al*. (2010) also reported that B would be more effective for pulse cultivation when it will be used with Zn fertilizer. The application of B is important when the concentration of B in the soil is less than 0.3 mg kg^{-1} (Ahlawat *et al*., 2007). The critical level of B with reference to crops in general was reported to be 0.15 to 0.20 ppm depending on soil types (BARC, 2005). Boron deficiency can be caused by high pH in the soil, the availability of B decreases when the pH is larger than 6.5–7.0 (Sims, 2000), which occur in highly leached sandy soils or in low organic matter soils. In fact, B has a critical role in growing tissues and any imbalance may inhibit the vegetative and reproductive stages in plants (Dell and Huang, 1997). Boron is also very important in cell division and in pod and seed formation. Soil, plant and climatic factors can influence interaction; under pot conditions with acidic soils at high moisture availability, Zn application was more efficient when it was applied in conjunction with B and Mo (Valenciano *et al*. 2010). The critical Zn concentrations in soils also vary from 0.48 to 2.5 mg kg^{-1} depending on soil type (Ahlawat *et al*., 2007) when there is less than to 1.1 mg kg^{-1} of Zn (DTPA extraction).

Moreover, farmers are losing interest in producing blackgram due to low income per unit of resources invested. So, therefore, attention should be given to increasing yield through the optimum doses of micronutrients as B and Zn. From the above facts, the present study was aimed to analyze the effect of B and Zn combination on germination and growth in terms of root, shoot length, number of leaves and branches, dry weight and yield in Madhupur Tract (AEZ–28). Therefore, growth and yield performance in field trial and germination including seedling vigor test in petridish were observed for seed quality to find out the optimum concentration of B and Zn. So, the present was carried out to investigate on the performances of growth, yield and seed quality of blackgram as influence by B and Zn with the following objectives–

i. To study the morpho–physiological, yield and quality characters of black gram as influence by various level of Zn and B as singly or combination.

ii. To expose the most effective interaction level between Zn and B to observe the growth, yield and quality of black gram.

CHAPTER II

REVIEW OF LITERATURE

Black gram (*Vigna mungo* L.) is a source of protein and also one of the most important pulse crops in Bangladesh. It is also an important and well recognized pulse crop. The literature on the effect of "Zinc (Zn)" and "Boron (B)" as micronutrient on growth, yield and quality of blackgram and other related pulse crops have been determined and are presented in this chapter. However, in the recent, many micronutrients are used for the observation of vegetative growth, seed quality and to boost the yield in various pulse crops. But, the literature on the use of different concentrations of "Zn and B" on blackgram are meager. So in this chapter, a survey of literature has been made on the effect of various micronutrients on morpho–physiological, seed quality and yield components of blackgram and related crops under the following headings:

2.1 Effect Zn and/or B on morphological and growth characters

Dashadi *et al*. (2013) conducted an experiment with three levels of P applied as TSP: 0, 50 and 100 kg ha^{-1}, and three levels of Zn applied as $ZnSO_4$: 0, 10 and 20 kg ha^{-1}. Results show that, P and Zn level had a significant effect on plant height. Zn_3 (20 kg ha^{-1}) and P_3 (100 kg ha^{-1}) produced most plant height due to the overcoming the limitation to plant nutrients through the application of appropriate fertilizers increased assimilate production and photosynthesis efficiency at the seed filling stage and also the increase carbohydrate and N metabolism which lead to higher vegetative growth.

Ali and Mahmoud (2013) studied to investigate the effect of salicylic acid (SA) and Zn foliar application on seed yield and yield components of mungbean under sandy soil conditions. The experiment was laid out in Randomized Complete Block Design (RCBD) using split–plot arrangement with three replications. Four SA concentrations (0, 50, 100 and 150 ppm) were assigned to the main plots. While, four foliar application concentrations of Zn (0, 300, 400 and 500 ppm) were applied to the sub–plots. The highest values of plant height and branches $plant^{-1}$ (76.7 cm and 5.2 branch $plant^{-1}$ in first season and 79.3 cm and 6.1 branch $plant^{-1}$ in second season) were registered at concentration of 150 ppm SA. Likewise, application of Zn significantly ($p\leq0.05$) increased plant height and number of branches $plant^{-1}$ in comparing with control plants and the superiority was due to application of 500 ppm Zn which produced the tallest plants and higher branches plant^{-1}, meanwhile, the difference between result obtained from 500 and 400 ppm Zn application was not significant in both seasons. The interaction between SA and Zn clearly showed significant ($p<0.05$) effects on the studying traits in both growing seasons. The tallest plants and the highest number of branches were registered when mungbean plants were treated with 150 ppm SA and 500 ppm Zn as a foliar application.

An experiment in factorial format based on RCBD was conducted by Salehin and Rahman (2012) to study the effects of Zn spray (0 and 1 g L^{-1}) and nitrogen (N) fertilizer (0, 25, 50 and 75 kg ha^{-1} pure N) on yield and yield components of *Phaseolus vulgaris*. At maturity plant height was measured. Results showed that, use of Zn spray had a significant effect in 1% probability level on plant height. Interaction effect of Zn spray and N fertilizer on plant height in 5% was significant.

A field experiment was conducted by Quddus *et al*. (2012) on *Chickpea–Mungbean–T. Aman* cropping pattern at Pulses Research Sub–Station, Madaripur under Low Ganges River Floodplain Soils (AEZ–12) during 2007–08 and 2008–09 to find out the suitable fertilizer doses for this pattern. Four treatments were set up for Chickpea and Mungbean *viz.* T_1= Recommended fertilizer dose as per FRG, 2005 BARC ($N_{15}P_{18}K_{10}S_5Zn_{0.5}B_{0.5}$); T_2= $N_{21}P_{23}K_{30}S_{18}Zn_2B_{1.5}$; T_3= $N_{23}P_{15}K_8$ and T_4=Control (without fertilizer). Average of two years, the plant height ranged from 36.95 to 44.15 cm. The highest plant height of Chickpea was recorded in T_2, which was statistically identical to T_1 and T_3 during 2008–09 and significantly higher over the other treatments during 2007–08. Average of two years, the highest plant height (45.38 cm) of mungbean was recorded in the treatment T_2, which was statistically identical to T_1. The lowest value (39.50 cm) was being noted in the treatment T_4.

Valenciano *et al*. (2011) reported that the Spain and Europe's leading chickpea (*Cicer arietinum*) producing country and chickpea is mainly cultivated on non–irrigated soils with low native fertility. The study was carried out from 2006 to 2008 in the province of Leo´ n, Spain, under acid soil field conditions, with the aim of determining whether the application of Zn, B and molybdenum (Mo) improved chickpea growth and yield on acid soils. The main factor was Mo application, with two levels of Mo, i.e. 0 and 241 g Mo ha^{-1}. The secondary factor was B application, with two levels of B, i.e., 0 and 241 g B ha^{-1}. The tertiary factor was Zn application, with five levels of Zn, i.e., 0, 120.5, 241.0, 482.0 and 964.0 g Zn ha^{-1}. Among the fertilizer application, Zn @ 241.0 g ha^{-1} produces the maximum weight of dry leaf–stem (0.56 g plant^{-1}), pod dry weight (8.82 g plant^{-1}) and total dry matter weight (14.97 g plant^{-1}), but dry weight of root had higher (0.62 g plant^{-1}) in higher application of Zn (482.0 g ha^{-1}). In contrast, B_1 (241.0 g ha^{-1}) and Mo_1 (241.0 g ha^{-1}) had also showed greater performance on root (0.57 and 0.59 g plant^{-1}), leaf–stem (5.26 and 5.40 g plant^{-1}), pod dry weight (8.17 and 8.75 g plant^{-1}) and total dry matter weight (14.01 and 14.74 g plant^{-1}).

Quddus *et al*. (2011) studied to evaluate the effect of Zn and B on the yield and yield contributing characters of mungbean (*Vigna radiata* L. Wilczek) and to find out the optimum dose of Zn and B for yield maximization. There were four levels of Zn (0, 0.75, 1.5, and 3.0 kg ha^{-1} and B (0, 0.5, 1.0, and 2 kg ha^{-1}) along with a blanket dose of N_{20} P_{25} K_{35} S_{20} kg ha^{-1}. Among the treatments, the highest plant height 47.8 cm and 44.0 cm were recorded with Zn level 1.5 kg ha^{-1} in the year of 2008 and 2009, respectively, which were statistically identical with T_4 treatment (3.0 kg Zn ha^{-1}) for both the years, but statistically significant to others.

Valenciano *et al*. (2010) reported that Spain is the main chickpea (*Cicer arietinum*) producing country in Europe, despite there are few studies on micronutrient application to chickpea. The response of chickpea to the applications of Zn, B and Mo was studied in pot experiments with natural conditions and acidic soils in northwest Spain from 2006 to 2008 following a factorial statistical pattern (5×2×2) with three replications. Five concentrations of Zn (0, 1, 2, 4 and 8 mg Zn pot^{-1}), two concentrations of B (0 and 2 mg B pot^{-1}), and two concentrations of Mo (0 and 2 mg Mo pot^{-1}) were added to the pots. Chickpea responded to the Zn, B and Mo applications. There were differences between soils. The mature plants fertilized with Zn, with B and with Mo had a greater total dry matter production.

An experiment was conducted by Kaisher *et al*. (2010) to investigate the effect of sulphur (S) on yield and protein content of mungbean, variety BARI Mung–5. The plant height was significantly influenced by S and its application. The tallest plant was found with 30 kg S ha^{-1} whereas the shortest was found in control. The result showed that plant height increase up to 30 Kg S ha^{-1} and after that to decreases. The result might be due to the fact that S is involved in the formation of chlorophyll and thereby encourages vegetative growth resulting increase in plant height. The plant height varied significantly due to B level. The tallest plant was found with 5 kg B ha^{-1} and the shortest from control. Boron level more than 5 kg ha^{-1} the plant height was decreased. It may be due to B, which plays on important role in the development and differentiation of tissue, cell division and nitrogen absorption from the soil, enhance plant growth, ultimately plant height increased. The result indicates that S and B levels influenced the plant height individually and by their combination. Similar results were also obtained by the application of S and B in respect of branches production $plant^{-1}$. The result might be due to S encourages the vegetative growth, so it increases the branches $plant^{-1}$. They stated that application of B increases number of branches $plant^{-1}$. The branch $plant^{-1}$ was maximum with 30 kg S and 5 kg B ha^{-1}. Above result in could be concluded that S and B level individually affect branches plant but not by their interaction.

A field experiment was conducted by Sharma *et al*. (2010) for three years during *Kharif* 2001, 2002 and 2003 at Agricultural Research station, Gulbarga (Karnataka) on shallow black soil. The experiment was laid out in RCBD with three replications. There were fourteen treatment combinations comprising of control, recommended dose of fertilizer (RDF), RDF+$ZnSo_4$ (15 and 25 kg ha^{-1}), RDF + Borax (5 and 10 kg ha^{-1}), RDF + sodium molybdate (1 kg and 2 kg ha^{-1}), RDF + chelated iron (1kg and 2 kg ha^{-1}), RDF + seed treatment ($ZnSo_4$ 4 g ha^{-1} seeds, Borax 4 g ha^{-1} seeds, sodium molybdate 4 gm kg^{-1} seeds and chelated iron 4 g kg^{-1} of seeds). Among the soil application, the treatment with RDF+$ZnSo_4$ 15 kg ha^{-1} recoded significantly higher plant height (196.1 cm), number of primary branches (14.3) and secondary branches (10.1) followed by the treatments RDF + $ZnSo_4$ @ 25kg ha^{-1} and RDF + Borax @ 10kg ha^{-1}. Among the seed treatments, RDF + seed treatment with sodium molybdate @ 4 g kg^{-1} seeds recorded significantly higher plant height (183.3cm), primary branches (13) and secondary branches (9.8) as compared to control.

Tekale *et al*. (2009) studied to examine the impact of B, Zn and IAA singly and in different treatments combinations at flowering and pod initiation stages of pigeon pea variety Asha and ICPL81–119. Seven treatment combinations consisting of T_1 (control), T_2 (IAA+B+Zn at flower initiation, FL), T_3 (IAA+B+Zn at pod initiation, PI), T_4 (IAA+B+Zn at both FL and PI stages), T_5 (IAA only at FL and PI stages), T_6 (B+Zn at FL and PI stages) and T_7 (IAA at FL and B+Zn at PI) were tested in RBD with three replications. The data revealed that plant height increased vigorously up to 90 days and then slowed up to maturity. The differences amongst treatments were significant at all the stages except S_1 stage. The treatment T_4 was at par with other treatments. Increase in plant height was mainly attributed due to higher shoot growth through cell elongation, cell differentiation and apical dominance promoted by IAA in addition with Zn and B. The data related to number of branches plant^{-1} revealed that treatment T_4 (18.32 and 21.27 at 50% podding and maturity stages respectively) gave the maximum value as compared to other treatments. These might be due to promotion of bud and branch development by the auxins whereas B and Zn application ultimately increased the availability of other nutrients. The leaf, stem, root and total dry matter plant^{-1} varied significantly at 125 and 180 DAS. Dry matter accumulation in leaf, stem, root and total dry matter was maximum in treatment T_4 followed by T_2 at all crop growth stages.

Paul (2009) reported that growth, nodulation, yield and yield contributing characters of blackgram were influence by the effect of N, Mo, B and *Bradyrhizobium* inoculant. *Bradyrhizobium* inoculation in presence of Mo and B recorded the highest root and shoot length.

Pandey *et al*. (2009) reported that black gram [*Vigna mungo* (L.) Hepper] cv. IPU 94 plants grown in sand culture with deficient Zn (0.1 µm zn) nutrition and those deprived of normal (1 µm) Zn supply at the initiation of flowering, showed decreased in dry matter production.

Khorgamy and Farnia (2009) reported that chickpea (*Cicer arietinum*) is one of the most important pulse crops in semi arid regions of Iran, India and China. Cultivars (Arman, Ilc–482), three levels of P applied (TSP): 70, 100 and 130 kg TSP ha^{-1}, and three levels of Zn applied as zinc sulphate: 0, 10 and 20 kg $ZnSO_4$ ha^{-1} were used for this study. Phosphorus and zinc fertilizer had a significant effect on plant height and P_3 (130 kg ha^{-1}) produced taller plants than other treatments while Zn_3 (20 kg ha^{-1}) also produced taller plants than other treatments. Cv. Arman produced the tallest plants over all treatments. Phosphorus and zinc fertilizers had also significant effect on number of main branch while P_3 (130 kg ha^{-1}) and Zn_3 (20 kg ha^{-1}) produced higher branch than other treatments. Cv. Arman produced the highest branch over all treatments.

Vishwakarma *et al*. (2008) revealed that in groundnut maximum plant height (60.33 cm) and number of branches (5.83 plant^{-1}) were recorded with application of borax as soil application.

Ved-Ram *et al.* (2008) found positive effects of N, P, K, S and Zn application on the plant height.

Dixit and Elamathi (2007) reported that foliar application of B (0.5%) in green gram increased the plant height (32.26 cm), number of nodules plant^{-1} (30.8) and dry weight plant^{-1} (12.90 g).

A field experiment was conducted by Bozoglu *et al*. (2007) to determine the effect of Zn and Mo fertilization on chickpea following a RCBD with three replications. Doses of Zn (Zn_0: 0, Zn_1: 1 ppm, Zn_2: 2 ppm) and Mo (Mo_0: 0, Mo_1: 0.05 ppm, Mo_2: 0.1 ppm) were applied on leaf when the plants were in vegetative stage. Variance analysis showed that application of Zn and Mo caused a significant change ($P < 0.01$) in plant height due to variation of years. In the first year the plant height was 33.36 cm and in the second year it increased to 49.21, in the reason might be due to higher rainfall (63 mm more rainfall) in the second year.

There was insignificant effect of Zn and Ni on the structure of leaves, the colour of leaves turn pale yellow in case of Zn treated plants due to chlorosis. The root and shoot lengths of black gram gradually decreased with increasing Ni concentrations. This may be due to the accumulation of Ni in plants (Sankar *et al*., 2006).

Thalooth *et al*. (2006) reported that the foliar application of Zn or K significantly increased all growth parameters. Differences among the effect of the foliar application were recorded. Potassium was superior in the features of area, number and weight of leaves plant^{-1} as well as number and weight of pods plant^{-1}, while Zn surpass the features of plant height and number of branches plant^{-1} and stem dry weight plant^{-1}. On the other hand, application of Mg insignificantly increases all growth parameters as compared with control plants. These results coincide with those obtained by Kassab (2005). It can be concluded also that the enhancement effect of spraying mungbean plants with Zn, K or Mg on growth parameters was very clear; hence treated plants resulted in taller, greater number and weight of leaves, branches and pods plant^{-1}. Such enhancement effect might be attributed to the favorable influence of these nutrients on metabolism and biological activity and its stimulating effect on photosynthetic pigments and enzyme activity which in turn encourage vegetative growth of plants (Michail *et al*., 2004).

Singaravel (2006) conducted a pot trial experiments to determine the effects of the different fertilizers on the growth and yield of groundnuts cv. VRI 2. He found that the recommended NPK in combination with 25 kg zinc sulfate ha^{-1}, 10 kg borax ha^{-1} and 10 t composted coir pith ha^{-1} gave the highest values for plant height, dry mater production during the flowering, post–flowering and harvesting stage of the crop.

Niranjana (2005) studied to investigate the effect of B (1.0 g kg^{-1} seed), Zn (2 and 4 g kg^{-1} seed) and Mo (2 and 4 g kg^{-1} seed) as seed treatments on the growth and yield of groundnut cv. KRG–1. He observed that the micronutrient showed significant effect on growth parameters. The Zn at 4 g + Mo at 2 g kg^{-1} seed treatment recorded the highest root length (13.66 cm) and its dry weight (887.0 mg) over the control.

Salam (2004) reported that B increased the plant growth, leaf area index, and root length and root nodules of bean.

An on–farm field experiment was conducted by Bhattacharya *et al*. (2004) to assess the effect of balanced fertilization on the performance of green gram (*Vigna radiata*) and black gram (*Vigna mungo*). Seven treatments included: a zero fertilizer control ($N_0P_0K_0$), recommended rates of 20 kg N, 40 kg P_2O_5, and 40 kg K_2O ha^{-1} applied as N, NP, NPK, NPK plus 10 kg borax ha^{-1}, NPK plus 1 kg ammonium molybdate ha^{-1}, and the complete NPKBMo treatment. Green gram variety, the data on plant height, dry matter production, and crop growth rate (CGR) of the two crops were recorded. The complete NPKBMo treatment produced significantly higher plants than any other treatment at 60 days after seeding (DAS). They also reported that the complete NPK+B+Mo treatment produced significantly higher dry matter production in green gram and black gram than any other treatment at 60 days after seeding (DAS). This treatment also enhanced the CGR values of the both crops.

2.2 Effect of Zn and/or B on yield and yield components

Shukla (2013) reported that the black gram (*Vigna mungo* L.) cv. Shyam was grown in refined sand till maturity (d 82) at two levels of Zn supply adequate (1 μM) Zn (control), and a deficient level (0.001 μM) of Zn supply. At deficient Zn, additional Zn was applied in two different modes: as $ZnSO_4$ (100 mg Zn L^{-1}) through seed priming for 4 h before sowing and root dipping treatment to 6 day old seedlings for 2 h before transplantation. The results showed that priming of grains with $ZnSO_4$ increased the vegetative as well as reproductive yield of plants grown at low Zn supply. Combined application of seed priming treatment with two foliar sprays of $ZnSO_4$ further enhanced the yield.

Dashadi *et al*. (2013) conducted an experiment with three levels of P applied as TSP: 0, 50 and 100 kg ha^{-1}, and three levels of Zn applied as $ZnSO_4$: 0, 10 and 20 kg ha^{-1}. Results show that, P level had a significant effect on number of pods $plant^{-1}$, 100- seed weight, seed yield and biological yield. Zinc applied to the soil, had a significant effect on number of pods $plant^{-1}$, 100-seed weight and seed yield. There was significant difference between the two cultivars tested and gachsaran was superior to flip 92–12l for 100- seed weight and seed yield. Gachsaran responded well to fertilizer treatment and environmental factors in dry land farming conditions. The significant positive effective of P fertilizer on yield and yield components indicates that P can be effectively applied to dry land farming system in Iran. Zinc fertilizer decreases pH of soil in dry areas and increases root absorption of minerals and improved plant growth regulator (IAA). Enhance plant nutrition increases assimilate production and photosynthesis efficiency at seed filling stage which lead to high yield and yield components.

An experiment was conducted by Pandey and Gupta (2013) to study the effect of foliar application of B on reproductive biology and seed quality of black gram. Black gram (*V. mungo* L. var. DPU–88–31) was grown under controlled sand culture condition at deficient and sufficient B levels. After 32 days of sowing B deficient plants were sprayed with three concentrations of B (0.05%, 0.1% and 0.2% borax) at three different stages of reproductive development. Foliar spray at all the three concentrations and at all stages increased the yield parameters like number of pods, pod size and number of seeds formed $plant^{-1}$. Foliar B application also improved the seed yield of black gram.

Ali and Mahmoud (2013) studied to investigate the effect of SA and Zn foliar application on seed yield and yield components of mungbean under sandy soil conditions. Foliar spray by SA, Zn and their interaction had a significant ($p \leq 0.05$) effect on number of pods plant^{-1}, number of seeds pod^{-1} and 1000–seed weight traits in the two growing seasons. SA concentration (150 ppm) which gave the highest values for these traits as following: 24.7, 10.7 and 41.0 for number of pods plant^{-1}, number of seeds pod^{-1} and 1000–seed weight, respectively in the first season and 27.8, 11.1 and 43.9 in the second season in the same order. Application of SA enhanced this trait in comparison with control plants (untreated) and the superiority in this respect to the high SA concentration (150 ppm) which gave the highest values 9.7 and 9.8 g for seed weight plant^{-1} in 2009 and 2010, respectively. The highest values of seed weight plant^{-1} were obtained when Zn foliar application was used at rate of 500 ppm. Application of SA at rate of 150 ppm produced the highest seed yield, 1793 and 1865 kg ha^{-1} in first and second seasons, respectively. This is a rational expectation since the same SA concentration gave the highest values of yield components and consequently seed yield. The maximum seed yields ha^{-1} (2000 and 2030 kg ha^{-1} in first and second seasons, respectively) were obtained when mungbean plants sprayed with 150 ppm SA and 500 ppm Zn with no–significant differences between this interaction and obtained seed yield from sprayed mungbean plants with 150 ppm SA and 400 ppm Zn in the two growing seasons. This is to be logic since the same interaction gained the highest values of yield components and consequently seed yield ha^{-1}.

Nalini and Bhavana (2012) reported that the response of Zn deficiency on reproductive yield and recovery through foliar application of Zn was determined in black gram, an important edible legume in India. Results revealed that foliar spray of Zn [0.01 and 0.5% $ZnSO_4$] improved not only the flowering, yield parameters like number, size and weight of pods and seeds. Foliar application of 0.5% $ZnSO_4$ after bud formation was most beneficial not only for reproductive yield but also seed Zn content.

An experiment in factorial format based on RCBD was conducted by Salehin and Rahman (2012) to study the effects of Zn spray (0 and 1 g L^{-1}) and N fertilizer (0, 25, 50 and 75 kg ha^{-1} pure nitrogen) on yield and yield components of *Phaseolus vulgaris*. In maturity time, seed yield, 100-seed weight, number of pods plant^{-1} and number of seeds pod^{-1} were measured. Results showed that, use of Zn spray had a significant effect in 1% probability level on all measured traits. Interaction effect of Zn spray and nitrogen fertilizer on number of seed pod^{-1} in 1% and on seed yield in 5% was significant and on other traits was non significant. The highest seed yield was obtained by Zn spray application with 1996 kg ha^{-1}.

A field experiment was conducted by Quddus *et al*. (2012) on *Chickpea–Mungbean–T.Aman* cropping pattern at Pulses Research Sub–Station, Madaripur under Low Ganges River Floodplain Soils (AEZ–12) during 2007–08 and 2008–09 to find out the suitable fertilizer doses for this pattern. Four treatments were set up for Chickpea and Mungbean *viz.* T_1= Recommended fertilizer dose as per FRG, 2005 BARC ($N_{15}P_{18}K_{10}S_5Zn_{0.5}B_{0.5}$); T_2= $N_{21}P_{23}K_{30}S_{18}Zn_2B_{1.5}$; T_3= $N_{23}P_{15}K_8$ and T_4=Control (without fertilizer). The maximum average number of pods plant^{-1} (46.15) of Chickpea was recorded in the treatment T_2 and the minimum value (36.55) was noted in the treatment T_4. The maximum and minimum number of seeds pod^{-1} was recorded in the treatment T_2 and T_4, respectively, in both the years. The average highest 100–seed weight (11.88 g) was also recorded in the treatment T_2. Similar treatment also observed the highest average seed yield (1524 kg ha^{-1}) and stover yield (4049 kg ha^{-1}). Similar results were also obtained for mungbean. The highest mean number of pods plant^{-1} (23.10), seeds pod^{-1} (9.01), 100–seed weight (5.76 g) was recorded in the treatment T_2. The highest average seed yield (2208 kg ha^{-1}) and stover yield (5121 kg ha^{-1}) were also found in the treatment T_2. The highest seed and stover yield in both the years were recorded in T_2 which were significantly higher than all other treatments

Valenciano *et al*. (2011) conducted an experiment on growth and yield of chickpea where the main factor was Mo application (0 and 241 g Mo ha^{-1}), secondary factor was B application with two levels (0 and 241 g B ha^{-1}) and tertiary factor was Zn (0, 120.5, 241.0, 482.0 and 964.0 g Zn ha^{-1}) Among them, Zn_3 (241.0 g ha^{-1}), B_1 (241.0 g ha^{-1}) and Mo_1 (241.0 g ha^{-1}) produces the higher results regarding to pods plant^{-1} (20.65, 19.02 and 20.57 g plant^{-1}, respectively), seeds pod^{-1} (triple similar 1.0 g plant^{-1}, respectively), 1000–seeds weight (293.19, 294.77 and 295.04 g plant^{-1}, respectively) and yield (6.80, 6.30, 6.73 g plant^{-1}).

Quddus *et al*. (2011) studied to evaluate the effect of Zn and B on the yield and yield contributing characters of mungbean (*Vigna radiata* L. Wilczek) and to find out the optimum dose of Zn and B for yield maximization. There were four levels of Zn (0, 0.75, 1.5, and 3.0 kg ha^{-1} and B (0, 0.5, 1.0, and 2 kg ha^{-1}) along with a blanket dose of N_{20} P_{25}

K_{35} S_{20} kg ha^{-1}. The experiment was laid out in RCBD with three replications. Results showed that the combination of $Zn_{1.5}B_{1.0}$ produced significantly higher yield (3058 kg ha^{-1}) and (2631 kg ha^{-1}, in the year 2008 and 2009, respectively. The lowest yield (2173 kg ha^{-1}) and (1573 kg ha^{-1}) were found in control (Zn_0B_0) combination in the year 2008 and 2009, respectively. The combined application of Zn and B were observed superior to their single application in both the years.

Roy *et al*. (2011) conducted an experiment where foliar or soil plus foliar methods of Zn fertilization increased yield attributes including seed pod^{-1}, pod plant^{-1}, 100-seed weight, both seed and straw yield and uptake of Zn in green gram over control irrespective of genotypes. The maximum increase in all parameters studied was found in the soil plus foliar application method.

Valenciano *et al*. (2010) studied to response of chickpea to the applications of Zn, B and Mo was studied in pot experiments. Five concentrations of Zn (0, 1, 2, 4 and 8 mg Zn pot^{-1}), two concentrations of B (0 and 2 mg B pot^{-1}), and two concentrations of Mo (0 and 2 mg Mo pot^{-1}) were added to the pots. Harvest Index (HI) improved with the Zn application and with the Mo application. The highest HI was obtained with the $Zn_4 \times B_2 \times Mo_2$ treatment (60.30%) while the smallest HI was obtained with the $Zn_0 \times B_0 \times Mo_0$ treatment (47.65%). The Zn, B and Mo applications improved seed yield, mainly due to the number of pods plant^{-1}. This was the yield component that had the most influence on, and the most correlation with seed yield. The highest seed yield was obtained from the $Zn_4 \times B_2 \times Mo_2$ treatment (4.00 g plant^{-1}) while the lowest was obtained from the $Zn_0 \times B_0 \times Mo_0$ treatment (2.31 g plant^{-1}). There was a low interaction between the three micronutrients. The Zn application was more efficient when it was applied with both B and Mo.

An experiment was conducted by Kaisher *et al*. (2010) to investigate the effect of S on yield and protein content of mungbean, variety BARI Mung–5. It appeared that S at 30 kg and B at 5 kg ha^{-1} significantly increased number of pods plant^{-1}, number of seeds pod^{-1}, 1000–seeds weight, seed yield and protein content (%). The control (0 kg S and B) had the poorest performance in respect of yield and protein content of mungbean seed.

A field experiment was conducted by Sharma *et al*. (2010) for three years during *Kharif* 2001, 2002 and 2003 at Agricultural Research station, Gulbarga (Karnataka) on shallow black soil. The experiment was laid out in RCBD with three replications. There were fourteen treatment combinations comprising of control, recommended dose of fertilizer (RDF), RDF+$ZnSo_4$ (15 and 25 kg ha^{-1}), RDF+Borax (5 and 10 kg ha^{-1}), RDF+sodium molybdate (1 kg and 2 kg ha^{-1}), RDF+chelated iron (1kg and 2 kg ha^{-1}), RDF+seed treatment ($ZnSo_4$ 4 g ha^{-1} seeds, Borax 4 g ha^{-1} seeds, sodium molybdate 4 gm kg^{-1} seeds and chelated iron 4 g kg^{-1} of seeds). The results revealed that the seed yield was significantly higher with RDF+$ZnSo_4$ @15 kg ha^{-1} (13.73 t ha^{-1}) followed by RDF+$ZnSo_4$ @ 25 kg ha^{-1} (13.53 t ha^{-1}) and RDF+seed treatment with sodium molybdate @ 4 g kg^{-1} seed (12.42 t ha^{-1}) as compared to control (7.76 t ha^{-1}). All the yield contributing characters *viz.*, number of pods $plant^{-1}$, number of seeds pod^{-1}, 100-seed weight and protein content were increased significantly.

Valenciano *et al*. (2009) also obtained similar results using the same types of soils but with different environmental conditions. The analysis of the variance established that the environment. Zinc interaction only had a low significant effect on the number of seed pod^{-1} and on the 1000–seed weight, but there was no significant difference on yield.

Tekale *et al*. (2009) studied to examine the impact of B, Zn and IAA singly and in different treatments combinations at flowering and pod initiation stages of pigeon pea variety Asha and ICPL81–119. Seven treatment combinations consisting of T_1 (control), T_2 (IAA + B + Zn at flower initiation, FL), T_3 (IAA + B + Zn at pod initiation, PI), T_4 (IAA + B + Zn at both FL and PI stages), T_5 (IAA only at FL and PI stages), T_6 (B + Zn at FL and PI stages) and T_7 (IAA at FL and B + Zn at PI) were tested in RCBD with three replications. It was interesting to notice that application of T_4 (IAA + B + Zn at FL and PI stages) showed remarkable improvement in yield attributing traits as compared to T_2 (IAA + B + Zn at FL). The data related to seed yield shows that the treatments differed significantly. Highest value was noted in T_4 (24.52 g $plant^{-1}$) whereas T_6 was less effective with value 19.49 g $plant^{-1}$. Data on harvest index exhibited that all the treatments differed statistically. The maximum value was obtained with T_4 (35.78) and the least effect was seen in T_6 (29.18). These might be due to the fact that IAA promotes the prevention of pod abscission and cell elongation at suppression of abscission of pod was the major determining factor of the seed yield.

Pandey *et al*. (2009) also reported that Zn deficiency led to decrease in number of pods, seeds pod^{-1} and seed mass, altered seed coat topography and reduced seeds germinability. Low seed yield under Zn deficiency is attributed to a role of Zn to fertilization and development of seeds.

Manonmani and Srimathi (2009) studied on the effects of the foliar application of $ZnSO_4$ (1.0%; T_1), Borax (1.0%; T_2), $FeSO_4$ (1.0%; T_3), $MnSO_4$ (1.0%; T_4), Na_2MoO_4 (1.0%; T_5), DAP [Diammonium phosphate] (2.0%; T_6), urea (1.0%; T_7) and KCl (1.0%; T_8) on blackgram (cv. APK 1) seed yield and quality were studied in Bhavanisagar, Tamil Nadu, India. Foliar spraying was conducted at the initial flowering and 50% flowering stages. DAP, followed by urea, resulted in the greatest 100–seed weight (5.6 and 5.5 g, respectively) and seed yield (1240 and 1040 kg ha^{-1}).

Kumar and Singh (2009) reported that balanced application of N, P, K, S, and Zn significantly increased the yield (2154 kg ha^{-1}) of mungbean.

Biswas *et al.* (2009) found similar results where fertilizer management practice ($N_{20}P_{20}K_{20}S_{10}Zn_2$) favoured seed yield (1214 kg ha^{-1}).

Khorgamy and Farnia (2009) reported that chickpea (*Cicer arietinum*) is one of the most important pulse crops in semi arid regions of Iran, India and China. A factorial, split–plot experiment, within a RCBD with three replications was investigated on the effects of P and Zn fertilization on the yield and yield components of Chickpea (*Cicer arietinum*). Cultivars (Arman, Ilc–482) were allocated to main plots. Sub–plot treatments were three levels of P applied as triple super phosphate (TSP): 70, 100 and 130 kg TSP ha^{-1}, and three levels of Zn applied $ZnSO_4$: 0, 10 and 20 kg $ZnSO_4$ ha^{-1}. Results show that Arman had higher seed yield (3500 kg ha^{-1}) and biological yield (total dry matter) than IIc–482. E.g. Both P and Zn had significant effects on 100-seed weight, seed yield, biological yield, Zn concentration (grain) and protein content (grain); while Zn also had a significant effect on number of pods $plant^{-1}$, number of seeds pod^{-1}, harvest index and P concentration (grain). The interaction between P and Zn for seed yield and biological yield were significant.

A pot experiment was conducted by Paul (2009) to study the effect of N, Mo, B and *Bradyrhizobium* inoculant on growth, nodulation, yield and yield contributing characters nitrogen uptake of black gram. *Bradyrhizobium* inoculation in presence of Mo and B recorded the highest root and shoot length, seed and stover yield, yield attributes, N and protein content of black gram compared to non–inoculated control. Molybdenum and B performed better results. This result indicated that the use of *Bradyrhizobium* inoculation with Mo and B appeared to be an effective method for successful black gram production.

Ved-Ram *et al.* (2008) found positive effects of N, P, K, S and Zn application on the pods plant^{-1}. They also observed that the application of N, P, K, S, and Zn nutrients favoured the seeds pod^{-1} and 1000–seed weight.

The highest number of pods plant^{-1} (26.66), pod and kernel yield (25.46 and 16.34 t ha^{-1}, respectively) were recorded with application of borax as soil application in groundnut (Vishwakarma *et al*., 2008).

The crop yield increased when the application of Zn was increased, and the crop yield increased even more when both the Zn and the Mo were applied at the same time. There was also a low significant Zn, B and Mo interaction on seed yield. The highest seed yield was obtained from the Zn_4, B_2 and Mo_2 treatment. The beneficial effect of the combined application of these micronutrients (Zn, B and Mo) has been reported with chickpea that grow in calcareous soil (Jahiruddin, 2008). The application of Zn was more efficient when it was applied with B and Mo.

A field experiment was conducted by Shanti *et al*. (2008) to study the effect of various levels, methods of application and residual effect of Zn on yield, nutrient concentration and uptake of black gram (*Vigna mungo*). Twelve treatments *viz.* T_1: Control (Zn_0), T_2: 12.5 kg $ZnSO_4$ ha^{-1} to paddy crop, T_3: 25 kg $ZnSO_4$ ha^{-1} to paddy crop, T_4: 50 kg $ZnSO_4$ ha^{-1} to paddy crop, T_5: 12.5 kg $ZnSO_4$ ha^{-1} to black gram, T_6: 25 kg $ZnSO_4$ ha^{-1} to black gram, T_7: 50 kg $ZnSO_4$ ha^{-1} to black gram, T_8: 0.2% spraying of $ZnSO_4$ at 25 days after sowing, T_9: 0.2% spraying of $ZnSO_4$ at flowering of black gram, T_{10} : 0.2% spraying of $ZnSO_4$ at pod formation of black gram, T_{11}: T_8 + T_9, T_{12} : absolute control (no N,P,K and Zn to either crops) were used for this experiment. The application of Zn at all levels significantly increased the seed and haulm yields of black gram over control. Higher seed yields receiving with directly $ZnSO_4$ greater which was 17.7% higher than those of foliar treatments. The maximum seed yield during both the years was recorded in treatment T_6, and T_7 which received $ZnSO_4$ @ 25 kg and 50 kg ha^{-1} through soil application to black gram crop. The increase in seed and haulm yield of black gram due to Zn might be attributed to the reason that, Zn shows beneficial effects on chlorophyll content and so it indirectly influences the photosynthesis and reproduction.

Zinc increased growth and yield which was mainly due to an increase in the number of pods plant^{-1}, with the application of Zn when the soil had high moisture availability. The increase in yield was the result of the increase in the number of pods per plant, which is the same as other leguminous plants (Valenciano *et al*., 2007).

Reddy *et al*. (2007) studied with pigeonpea variety ICPL-87119 at Regional Agricultural Research Station (RARS), Warangal, Andhra Pradesh, India during *kharif* season in 2005–06 under rainfed conditions. The experiment was laid out in RCBD with three replications with ten treatments T_1: 20, 50, 20 and 20 kg ha^{-1} of N, P_2O_5, K_2O and S; T_2: T_1 + B at 10 kg ha$_{-1}$; T_3: T_1 + B at 20 kg ha^{-1}; T_4: T_1 + sodium molybdate at 1.5 kg ha^{-1}; T_5: T_1 + sodium molybdate at 3.0 kg ha^{-1}; T_6: T_1 + chelated Fe at 2.0 kg ha^{-1}; T_7: T_1 + chelated Fe at 3.0 kg ha^{-1}; T_8: T_1 + seed treatment with B at 4 g kg^{-1} seed; T_9: T_1 + seed treatment with sodium molybdate at 4 g kg^{-1} seed; and T_{10}: T_1 + seed treatment with chelated Fe at 4 g kg^{-1} seed Application of N, P, K and S at 20, 50, 20 and 20 kg ha^{-1} along with sodium molybdate at 3.0 kg ha^{-1} to soil has recorded significantly higher yield (2.3 t ha^{-1}) and was on par with all other treatments, except application of recommended doses of N, P, K and S (RDF) at 20, 50, 20 and 20 kg ha–1 (1.9 t ha^{-1}). Similar trend was observed in case of pods plant^{-1}.

Dixit and Elamathi (2007) reported that foliar application of B (0.2%) in greengram increased the number of pods plant^{-1} (181), 1000–seeds weight (28.7 g), grain yield (7.53 t ha^{-1}) and haulm yield (30.0 t ha^{-1}).

A field experiments on conducted by Shil *et al*. (2007) on chickpea (cv. BARI Chola–5) in Calcareous Dark Grey Floodplain Soil under AEZ-11 at Jessore and Non Calcareous Grey Floodplain Soil under AEZ-13 at Rahmatpur during the rabi season of 2001–2002 and 2002–2003. The objective was to find out the optimum dose of B and Mo for yield maximization. Four levels each of B (0, 1, 2 and 2.5 kg ha^{-1}) and Mo (0, 1, 1.5 and 2 kg ha^{-1}) along with a blanket dose of $N_{20}P_{25}K_{35}S_{20}Zn_2$ kg ha^{-1} & cowdung 5 t ha^{-1} were applied in this study. The combination of $B_{2.5}\times Mo_{1.5}$ kg ha^{-1} and $B_{2.5}\times Mo_1$ kg ha^{-1} produced significantly higher yield in both the years of study at Jessore and Rahmatpur, respectively.

The said treatments produced the highest mean yields of 2.10 and 1.49 t ha^{-1} for Jessore and Rahmatpur, respectively, which was around 53% higher over control ($B_0 \times M_0$). The combined application of both B and Mo were found superior to their single application even though B played major role in augmenting the yield. However, from the regression analysis, the optimum treatment combination was calculated as $B_{2.34}$ $Mo_{1.44}$ kg ha^{-1} for Jessore and $B_{2.20}$ $Mo_{1.29}$ kg ha^{-1} for Rahmatpur.

A field experiment was conducted by Pesken *et al*. (2007) to determine the effect of Zn and Mo fertilization on chickpea following a RCBD with three replications. Doses of Zn (Zn_0: 0, Zn_1: 1 ppm, Zn_2: 2 ppm) and Mo (Mo_0: 0, Mo_1: 0.05 ppm, Mo_2: 0.1 ppm) were applied on leaf when the plants were in vegetative stage. Variation of years on all investigated characters was statistically significant. Applied Zn or Mo failed to show any significant effect on any parameter. It was found that effect of Zn and Mo interaction was statistically significant ($p < 0.01$) on the seed yield. The highest seed yield resulted from Zn_2 (2 ppm) and Mo_0 interaction. This was followed by Zn_1 (1 ppm) and Mo_1 (0.05 ppm) and Zn_1 and Mo_2 doses showing no statistical differences from each other.

A field experiment was conducted by Gupta *et al*. (2007) at the Fertilizer Research Station of Chandra Sekhar Azad University of Agriculture and Technology in Pura, Uttar Pradesh, during the summer season (March to June) of 2005. A maximum seed yield of 1254 kg ha^{-1} was obtained under T_9 ($N_{22}P_{60}K_{60}S_{20}Zn_{15}B_5$). Yield under T_9 was 123% above the control. Treatments supplying less N (T_8: $N_{15}P_{60}K_{60}S_{20}Zn_{15}B_5$) or no Zn ($T_{11}$: $N_{22}P_{60}K_{60}S_{20}Zn_0B_5$) provided yields that were statistically equivalent to T_9. Stover yield followed a similar trend and varied between 1068 kg ha^{-1} in the control to 2006 kg ha^{-1} under T_9.

A field experiment was conducted by Bozoglu *et al*. (2007) to determine the effect of Zn and Mo fertilization on chickpea following a RCBD with three replications. Doses of Zn (Zn_0: 0, Zn_1: 1 ppm, Zn_2: 2 ppm) and Mo (Mo_0: 0, Mo_1: 0.05 ppm, Mo_2: 0.1 ppm) were applied on leaf when the plants were in vegetative stage. Number of pods $plant^{-1}$ is an important yield feature for pulses. The average number of pods $plant^{-1}$ was recorded to be 19.54 and 20.4 in the first and second year, respectively. Change in pods $plant^{-1}$ due to variation in year was not significant. In the second year, only 18.05 pods $plant^{-1}$ were obtained with no Zn. when Zn @ 2 ppm was applied, although the number increased to 22.59 but was not significant. The weight of 100-seed was 46.46 g in the first year and it decreased to 36.08 g in the second year. However, in the second year, this value increased to 1226.5 kg. Application of Zn showed an increase in yield with rate but the increase was not statistically significant. As year averages, the yield of Damla–89 chickpea was 1028, 1078, 1158.2 kg/ha due to application of Zn (2 ppm). Supply of Mo resulted an increase in yield up to 0.05 ppm and thereafter a reduction in the same was occurred (Mo_0: 1044, Mo_1: 1157.5, Mo_2: 1062.5 kg). The effect of Zn×Mo interaction on the seed yield was significant ($p < 0.01$). The highest seed yield was obtained from $Zn_2 \times Mo_0$ treatment (1225 kg ha^{-1}). The lowest seed yield was obtained from $Zn_1 \times Mo_0$ (853.8 kg ha^{-1}) treatment and $Zn_1 \times Mo_0$ interaction showed that Zn was more effective to increase the yield than Mo.

Two field experiments were carried out by Tahlooth *et al*. (2006) to study the effect of foliar application of Zn, K or Mg on growth, yield and yield components and some chemical constituents of mungbean plants grown under water stress conditions. Irrespective to water stress, foliar application of Zn, K, or Mg significantly increased all the yield characters compared with control plants. Potassium foliar application had the greatest stimulatory effect on pods number $plant^{-1}$, pods dry weight, number of seeds pod^{-1}, seeds dry weight $plant^{-1}$, seed index and seed yield kg fed^{-1}. On the other hand, Zn application was superior with respect to straw and biological yield fed^{-1}.

Singaravel *et al*. (2006) found that the recommended NPK in combination with 25 kg $ZnSO_4$ ha^{-1}, 10 kg borax ha^{-1} and 10 t composted coir pith ha^{-1} gave the highest number of pods $plant^{-1}$, crop yield, and N, P, K, Zn and B uptake of the groundnuts also increased.

Niranjana *et al*. (2005) conducted a field experiment to investigate the effect of B (1.0 g kg^{-1} seed), Zn (2 and 4 g kg^{-1} seed) and Mo (2 and 4 kg^{-1} seed) as seed treatments on the growth and yield of groundnut cv. KRG–1 on Alfisol, which was deficient in Zn (0.46 mg kg^{-1}) and Mo (0.032 mg kg^{-1}). He observed that the micronutrient showed significant effect on yield, oil content and growth parameters. The Zn at 4 g + Mo at 2 g kg^{-1} seed treatment recorded the highest pod yield of 24.99 t ha^{-1} over the control.

Nassar (2005) conducted an experiment to evaluate the effect of foliar application of B, Zn, Mn and Fe on the seed and pod yields of groundnut as well as on the nutrient, oil and protein content of seeds. Boron was applied at rates of 75, 150 and 300 mg $litre^{-1}$ as boric acid, whereas Zn, Mn and Fe were applied at rates of 150, 300 and 600 mg $litre^{-1}$ in EDTA from. Foliar spraying with 600 mg Fe, 600 mg Zn, 300 mg Mn and 150 mg B litre^{-1} gave the highest seed and pod yields.

Islam (2005) observed that seed yield of chickpea (cv. BARI Chola-5) increased significantly due to application of 1 to 1.5 kg B ha^{-1}. In these contexts, application of B and Mo in addition to essential major elements along with a maintenance dose of cowdung has gaining practical significance for boosting up the yield of chickpea.

Zinc deficiency decreases crop yield and delays crop maturity. Also, Zn deficiency reduces water use and water use efficiency (Khan *et al*., 2004) and also reduces nodulation and nitrogen fixation (Ahlawat *et al*., 2007), which contributes to a decrease in crop yield.

Janakiraman *et al*. (2004) conducted a field experiments to determine that groundnut growth and yield were significantly higher when Fe, Zn and B were applied with recommended doses of NPK fertilizers. Combined application of 50 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1}, 25 kg K_2O ha^{-1} along with $FeSO_4$ 10.0 kg ha^{-1}, $ZnSO_4$ @ 5.0 kg ha^{-1} and borax @ 1.0 kg ha^{-1} maximized the groundnut yield and net return.

Field experiments were conducted by Poongothai *et al*. (2004) with black gram var. COBG 593 (in 2000) and TMV 1 (in 2001) at Alandurai and Mathuvarayapuram in a red sandy loam soil for assessing the efficacy of soil application and seed treatment by Zn, B, S and Mo during 2000 and 2001. The results indicated that, soil application of 5 kg Zn + 1.5 kg B + 0.5 kg Mo + 40 kg S ha^{-1} increased the yield of both the varieties and the yield increase was more with COBG 593 (34.1%) than TMV 1 (21%) indicating the high responsiveness of COBG 593 to added fertilizers. Soil application is found to be the best when compared to seed treatment of Zn, B, S and Mo.

Chitdeshwari and Poongothai (2004) prevailed the response of groundnut to the soil application of Zn, B and S and Mo, and also the seed treatment with Zn, B and S. A substantial yield increase was obtained with the soil application of Zn @5 kg ha^{-1} in combination with B @ 1.0 kg ha^{-1} and S at 40 kg ha^{-1}. The yield increase over the control was 24.2% for TMV 7 and 14.8% for JL 24. Zinc had the most pronounced effect on yield, followed by S and B.

Bhattacharya *et al*. (2004) studied to assess the effect of balanced fertilization on the performance of greengram (*Vigna radiata*) and blackgram (*Vigna mungo*). Seven treatments included: recommended fertilizer as control ($N_0P_0K_0$) as N, NP, NPK, NPK plus 10 kg borax ha^{-1}, NPK plus 1 kg ammonium molybdate ha^{-1}, and the complete NPKBMo treatment. In both crops, plots receiving no fertilizer or N only exhibited similarly poor yields. Plots treated with the complete NPKBMo treatment returned the highest green gram yield (1,398 kg ha^{-1}). A similar yield response was observed in black gram although the response to micronutrients appeared less prominent. Balanced application of NPK along with B and Mo will be an effective solution for higher grain yield of pulses in red and lateritic soils. Adequate NPK fertilization increased green and black gram yields by 13% and 38% over the control. Further, inclusion of B and Mo improved yield by 38% for green gram and 50% for black gram over the control.

Application of 0.25 to 0.50 kg B ha^{-1} significantly increased pod yield of groundnut (Kumar, 2004).

Field experiments were conducted by Kalyanasundaram (2002), Tamil Nadu. It was found that foliar application of Penshibao (macro and micronutrient mixture) at 50 ml ha^{-1} along with plantozyme (liquid biofertilizer) recorded an additional grain yield of 214 Kg ha^{-1} (24.4%) in blackgram. Foliar application of 2% DAP was also followed.

Bharti *et al*. (2002) carried out a field experiment in Bihar, India during the winter of 1997–98 to observe the effects of B (0, 1.5 and 2.5 kg ha^{-1}) application on the yield and nutrition of Chickpea (cv. BG 256). They reported that the mean seed yield, and seed stover N and B content increased, whereas stover yield decreased with increasing B rates.

Ali *et al*. (2002) reported that yield losses of varying magnitude in chickpea, e.g., 22–50% due to Fe up to 100% due to B and 16–30% due to S. Genotypic differences in response to application of Fe, B and S have also been found among chickpea genotypes.

A field experiments were conducted by Singh *et al*. (2002) in sandy loam calcareous soil in Uttar Pradesh, India during 1995–96 to study the effect of B application on yield of pea (cv. Rachna) and blackgram (cv. PV–19). Boron was appliced as borax at the rates of 1, 2, 3 and 4 kg borax ha^{-1}, with a control. Application of borax up to 4 kg ha^{-1}

significantly increased the grain yield of blackgram. The maximum yield was 15.42 t ha^{-1} and minimum grain yield of 1.65 t ha^{-1} was found in the control. The additional grain yield over the control was 280, 431, 899 and 1377 kg ha^{-1} at 1.0, 2.0, 3.0 and 4.0 kg borax ha^{-1}, respectively. Application of B progressively increased the grain yield of pea from 510 to 1843 kg ha^{-1} up to 4 kg borax ha^{-1}.

Mishpra *et al*. (2001) conducted an experiment on the effect of nutrient management and plant growth regulators on the yield and economics of chickpea in Madhya Pradesh, India during the rabi season of 1998–99. Seeds and stover yields were higher in B and cephalexin treatments compared to the other growth regulator treatments. Boron and P with S treatments gave the highest net returns.

2.3 Effect of Zn and/or B on quality characters

Anita *et al*. (2012) studied to examine optimum concentration of B and Zn needed to mitigate the harmful effect of salinity at early establishment of seedlings including seed germination. Sterilized seeds of *Vigna radiata L. Wilczek* var. Pusa Vishal were germinated and grown under different levels of B (1×10^{-3} *mM* – 5×10^{-3} *mM*) and Zn (1×10^{-3} *mM* – 10×10^{-3} *mM*) under controlled conditions. The decrease was reverted with specific optimal concentration of B (3×10^{-3} *mM*) and Zn (4×10^{-3} *mM*). The optimum concentration of B and Zn were thus taken for further sand culture experiments based on maximum germination percentage.

Pandey and Gupta (2013) studied to study the effect of foliar application of B on reproductive biology and seed quality of black gram (*Vigna mungo*). After 32 days of sowing B deficient plants were sprayed with three concentrations of B (0.05%, 0.1% and 0.2% borax) at three different stages of reproductive development. Foliar B application improved the seed quality in terms of storage seed proteins (albumin, globulin, glutenin and prolamin) and carbohydrates (sugars and starch) in black gram.

Application of B and Zn elevated the germinability of seeds under NaCl stress, the germination percentage was maximum at 3×10^{-3} *mM* of B and 3×10^{-4} *mM* of Zn. The essentiality of B for growth and development of higher plants has been demonstrated earlier also (Herrera–Rodriguez *et al*., 2010).

Manonmani and Srimathi (2009) studied on the effects of the foliar application of $ZnSO_4$ (1.0%; T_1), Borax (1.0%; T_2), $FeSO_4$ (1.0%; T_3), $MnSO_4$ (1.0%; T_4), Na_2MoO_4 (1.0%; T_5), DAP [Diammonium phosphate] (2.0%; T_6), urea (1.0%; T_7) and KCl (1.0%; T_8) on blackgram (cv. APK 1) seed yield and quality were studied in Bhavanisagar, Tamil Nadu, India. DAP, followed by urea, resulted in the greatest germination (92 and 88%) and vigour index (3690 and 3256). The resultant seeds were stored under ambient conditions (28+2°C and 70+5% relative humidity) for 12 months. Treatment with DAP and urea maintained the storability of seeds, which were characterized by high germination rates (74 and 70%) and vigour index (2088 and 1820), up to 10 months of storage, whereas the control seeds maintained their viability only up to 8 months of storage.

The B and Zn potentiated the seed germination compared with that of control seeds. The B and Zn supplementation individually or together in pot experiments alleviated the salinity (100 *mM* NaCl) effect on germination, the optimum response was like as in case of petridish culture at 3×10^{-3} *mM* of B and 3×10^{-4} *mM* of Zn (Goldbach and Wimmer, 2007).

CHAPTER III

MATERIALS AND METHODS

The materials and methods of this research work were described in this chapter as well as on experimental materials, site, climate and weather, land preparation, experimental design, lay out, sowing of seeds, intercultural operations, crop sampling, data collection, harvest index etc within a period. Overall discussion about different levels Zn and B fertilizer on some morpho–physiological and yield contributing characters of black gram under the following headings:

3.1 Experimental site

The present research work was conducted at the research field of the Department of Agronomy, Sher–e–Bangla Agricultural University, Dhaka during the period from August, 2012 to December, 2012. The experimental area is located at 23.41^0 N and 90.22^0 E latitude and at an altitude of 8.6 m from the sea level.

3.2 Soil

The soil of the experimental area was to the general soil type series of shallow red brown terrace soils under Tejgaon series. Upper level soils were clay loam in texture, olive–gray through common fine to medium distinct dark yellowish brown mottles under the Agro–ecological Zone (AEZ– 28) and belonged to the Madhupur Tract (UNDP/FAO, 1988). The selected plot was above flood level and sufficient sunshine was available having available irrigation and drainage system during the experimental period. Soil samples from 0–15 cm depths were collected from experimental field. The analyses were done from Soil Resources Development Institute (SRDI), Dhaka. The experimental plot was also high land, fertile, well drained and having p^H 5.8. The physicochemical property and nutrient status of soil of the experimental plots are given in Appendix II.

3.3 Climate and weather

The experimental area is situated in the sub–tropical climatic zone and characterized by heavy rainfall during the months of April to September (Kharif Season) and scanty rainfall during the rest period of the year (Biswas, 1987). The Rabi season (October to

March) is characterized by comparatively low temperature and plenty of sunshine from November to February (SRDI, 1991). The detailed meteorological data in respect of air temperature, relative humidity, total rainfall and soil temperature recorded by the National Meteorological Research Centre, Dhaka during the period of study have been presented in Appendix I.

3.4 Crop: Blackgram (*Vigna mungo* L.)

3.4.1 Variety: BARI Mash–3

BARI Mash–3 was developed by Bangladesh Agricultural Research Institute (BARI) and it was released in 1996 by the National Seed Board for stable and high yield with combined resistant to YMV caused by the yellow mosaic virus and *Cercospora* leaf spot (CLS). Plant height of this variety ranges from 35–37 cm; maximum field duration from 70–75 days and average yield from 1400–1600 kg ha^{-1}. This variety possesses the special characteristics of photo–insensivity and synchrony in maturity. Leaves are trifoliate, alternate and green. Leaf pubescence is present. Petioles are short and purple–green. The corolla is yellowish–green. The raceme position is under the canopy. Mature pods are black with dense pubescence. Seeds are drum–shaped and blackish. It has a 100–seed weight of about 4.8 g. Because of its wide adaptability, the cultivar was recommended for three different blackgram growing seasons (kharif–II (August–October), kharif–I (February–May) and late rabi (January–April) for cultivation in all blackgram growing areas in Bangladesh. Seeds of BARI Mash–3 have 86.6% kernel content, but produce 78.5% head dhal (intact kernel after splitting) using the traditional method of dehulling. It takes about 22 minutes to cook and shows solid dispersion of 23.8%. BARI Mash–3 contains 26.5% protein and 46.8% carbohydrate (Bakr *et al*., 2004).

3.5 Experimental treatments

The experiment treatments consisted with two factors i.e. Zinc (Zn) and Boron (B) which were present are as follows:

Factor A: Zinc (Zn) level– 4 (four)

Zn_0 = 0 Kg ha^{-1}

$Zn_{1.25}$ = 1.25 Kg ha^{-1}

$Zn_{2.5}$ = 2.5 Kg ha^{-1}

$Zn_{3.75}$ = 3.75 Kg ha^{-1}

Factor B: Boron (B) level– 5 (five)

B_0 = 0 Kg ha^{-1}

$B_{0.5}$ = 0.5 Kg ha^{-1}

$B_{1.0}$ = 1.0 Kg ha^{-1}

$B_{1.5}$ = 1.5 Kg ha^{-1}

$B_{2.0}$ = 2.0 Kg ha^{-1}

3.6 Experimental design and layout

The experiment consisted with four levels of Zn and five levels of B and was laid out in a split-plot with three replications. Zinc and Boron levels were assign to main and sub-plot, respectively. The size of unit plot was 2.5 × 2.0 m where block to block and plot to plot distance was 0.50 and 0.50 m, respectively. Row to row and plant to plant distances were also 30 and 10 cm, respectively, in each plot. So, the total plot were 60 (Zn levels 4 × Boron levels 5 × Replication 3) which layout of plot was given in Appendix III.

3.7 Land preparation

Power tiller was used for the preparation of the experimental field. Then it was exposed to the sunshine for 5/6 days prior to the next ploughing. Thereafter, the land was ploughed and cross–ploughed and deep ploughing was obtained good tilth, which was necessary to get better yield of this crop. Laddering was done in order to break the soil clods into small pieces followed by each ploughing. All the weeds and stubbles were removed from the experimental field. The plots were spaded one day before planting and the whole amount of fertilizers were incorporated thoroughly befor planting according to the treatments of the present study and rest of the recommended amount (BARC fertilizer recommended guide, 2005) of fertilizer were used. The soil was treated with insecticides at the time of final ploughing. Insecticides Furadan 5G was used @ 8 kg ha^{-1} to protect young plants from the attack of mole cricket, ants, and cutworms.

3.8 Manures and fertilizers

Manures and fertilizer such as urea, TSP, MOP, H_3BO_4 and $ZnSO_4$ were used as source for N, P, K, B, and Zn, respectively. Zinc and Boron fertilizer were applied to each plot as per treatment while among other fertilizer were used as per recommended dose in those plots during final land preparation. The fertilizers were incorporated into soil by spading.

Fertilizers	Dose (ha^{-1})	Quantity $plot^{-1}$
Urea	20 kg	10 g
TSP	150 kg	75 g
MOP	50 kg	25 g

Source: BARI 2006 (Fertilizer Recommendation Guide)

3.9 Seed treatments

For each treatment dry clean and homogenous air–dried seeds with about 12% moisture content were used. For each plot seeds were sown into the line for this experiment.

3.10 Seed sowing

Seeds of BARI Mash–3 varieties were hand sown in the experimental plot. Seeds were sown on the first week of August, 2012. The row to row and plant to plant distances were 30 and 10 cm, respectively.

Seeds were placed at about 3 to 4 cm depth from the soil surface. Few seedlings were grown in the border of the plots as stock seedling for gap filling subsequently.

3.11 Intercultural operations

3.11.1 Thinning out

Emergence of seedling was completed within 7 days after sowing (DAS. Over crowded seedlings were thinned out two times. First thinning was done after 15 days of sowing which is done to remove unhealthy and lineless seedlings. The second thinning was done 10 days after first thinning.

3.11.2 Gap filling

Seedlings were transferred to fill in the gaps where seeds failed to germinate. The gaps were filled in within two weeks after germination of seeds.

3.11.3 Weeding

First weeding was done at 20 DAS and second one at 35 DAS to keep the plots free from weeds and to keep the soil loose and aerated.

3.11.4 Irrigation

The irrigation was done for three times at 20 DAS, 35 DAS and 50 DAS through flood irrigation method. Water application was continued till soil saturation.

3.11.5 Disease and pest management

The research field looked nice with normal green plants. Field was observed time to time to detect visual difference among the treatments and any kind of infestation. The experimental crop was not infected with any disease and no fungicide was used. Hairy caterpillars attacked the young plants and accumulated on the lower surface of leaves where they usually sucked juice of green leaves. Borers also attacked the pods. They attacked at the early growing stages of seedlings.

To control these pests, the infected leaves were removed from the stem and destroyed together with the insects by hand picking. Beside, spraying pyriphos controlled these insects. The insecticide was sprayed three times at seven days interval.

3.12 Harvesting and threshing

Harvesting of the crop was done after 65 days of sowing for data collection when about 80% of the pods attained maturity. The morphological, growth and yield attributes crop sampling was done at harvest stage. Data were recorded on 1 m^2 area of the middle portion of each plot for average results. The harvested plants of each treatment were brought to the cleaned threshing floor and separated pods from pants by hand and allowed them for drying well under bright sunlight.

3.13 Crop sampling and data collection

The data of the different parameters of black gram were collected from randomly selected five plant samples which collected from the middle portion of the plot (1 m^2). The harvested plants were kept for yield. The sample plants were uprooted carefully from the soil with nirani so that no seeds were dropped into the soil and then cleaned, dried on floor and separated pods from pants by hand and allowed them for drying well under bright sunlight. Finally, grain weights were taken on individual plot basis at moisture content of 12% and converted into t ha^{-1}. The yield of dry stover was also taken. The data on growth and yield parameters were recorded from at harvest stage. The leaf area of each sample was measured by LICOR automatic leaf area meter (LICOR– 2000, UK) before drying and then converted into LAI. At final harvest, data on some morpho–physiological, yield components and yield were also collected. A brief outline of the data recording on morpho–physiological and yield contributing characters are given below:

3.13.1 Morphological characters

3.13.1.1 Plant height (cm)

Plant height was measured in centimeter by a meter scale at 15 days interval from 20 DAS up to harvest (65 DAS) from the ground surface to the top of the main shoot and the mean height was expressed in cm.

3.13.1.2 Length of root (cm)

The length of root was recorded at 20, 35, 50 DAS and at harvest (65 DAS) from the randomly selected five plants of each replication plot. Length of root data was recorded in cm.

3.13.1.3 Number of leaves plant^{-1}

Number of leaves plant^{-1} was counted at the time of harvest and then the randomly selected first simple leaf and the subsequent compound leaves were counted and recorded.

3.13.1.4 Number of branch plant^{-1}

Number of branches plant^{-1} data was also recorded at harvest time where all the primary and secondary branches were developed in each plant.

3.13.1.5 Total dry matter (TDM)

The plant parts such as shoot including leaves and roots were detached and were kept separately in oven at 80±2^{O} C for 72 hours. The oven dried samples were weighed (g) for dry matter production. The total dry matter production was calculated from the summation of shoots and roots.

3.13.2 Growth characters

3.13.2.1 Leaf Area Index (LAI)

Leaf area index was measured by dividing leaf area per plant with surface area (cm^2) covered by the plant.

$$\text{LAI} = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Soil surface area covered by each plant (cm}^2\text{)}}$$

3.13.2.2 Absolute Growth Rate (AGR)

Absolute Growth Rate (AGR) values at different growth stages were calculated using the following formula–

$$AGR = \frac{W_2 - W_1}{T_2 - T_1} \text{ g cm}^{-2}\text{day}^{-1}$$

Where, W_1= Total dry matter production at previous sampling date

W_2= Total dry matter production at current sampling date

T_1= Date of previous sampling

T_2= Date of current sampling

LA= Leaf area

Log_e= Natural logarithm

3.13.2.3 Relative Growth Rate (RGR)

The relative growth rate (RGR) values at different growth stages were calculated using the following formula–

$$RGR = \frac{Log_e W_2 - Log_e W_1}{T_2 - T_1} \text{ g cm}^{-2}\text{day}^{-1}$$

Where, W_1= Total dry matter production at previous sampling date

W_2= Total dry matter production at current sampling date

T_1= Date of previous sampling

T_2= Date of current sampling

Log_e= Natural logarithm

3.13.2.4 Crop Growth Rate (CGR)

The crop growth rate values at different growth stages were calculated using the following formula–

$$CGR = \frac{1}{GA} \times \frac{W_2 - W_1}{T_2 - T_1} \text{ g m}^{-2}\text{day}^{-1}$$

Where, W_1= Total dry matter production at previous sampling date

W_2= Total dry matter production at current sampling date

T_1= Date of previous sampling

T_2= Date of current sampling

GA= Ground area (m^2)

3.13.3 Yield and yield contributing characters

3.13.3.1 Number of pods plant$^{–1}$

The pods from all the branches of the pre–selected five plants were counted and the number of pods plant$^{–1}$ was calculated from their mean values.

3.13.3.2 Pod length (cm)

Pod length was measured in centimeter (cm) scale from randomly selected average five pods of the selected plants. Mean value of them was recorded as treatment wise.

3.13.3.3 Number of seeds pod$^{–1}$

Number of seeds pod^{-1} was recorded after harvesting of the crop from the ten randomly selected pods from ten pre–selected plants was counted. The seeds pod^{-1} was calculated from their mean values.

3.13.3.4 1000– seed weight

The weight of 1000 randomly selected oven dried (temperature 60^{O}C for 48 hours) seeds was measured in gram by an electric balance.

3.13.3.5 Grain yield (t ha^{-1})

The seed yield per plot was measured by threshing and separating grain from the central 1m^2 areas of unit plot and then seed yield was expressed in t ha^{-1}.

3.13.3.6 Straw yield (t ha^{-1})

The stover weight was taken from the remaining plant parts after threshing and separating grain from the plants collected from the central $1m^2$ areas of unit plot by threshing and then stover yield was expressed in t ha^{-1}.

3.13.3.7 Biological yield

The summation of economic yield (grain yield) and biomass yield (stover yield) was considered as biological yield. Biological yield was calculated by using the following formula:

Biological yield= Grain yield + stover yield (dry weight basis)

3.13.3.8 Harvest index

It is the ratio of economic yield to biological yield and was calculated with the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.13.4 Chemical analysis of plant samples

3.13.4.1 Preparation of seed sample

The seed samples were sun dried and then packed in polythene bag by proper labeling. These labeled packed samples were immediately sent to **Bangladesh Council of Scientific and Industrial Research (BCSIR)**, Dhaka for determination of N, P, K and S concentration. The methods were as follows:

3.13.4.2 Digestion of plant samples with nitric–perchloric acid

A sub–sample weighing 0.5 g was transferred into a dry, clean 100 ml kjeldahl flask. A 10 ml of di acid mixture (HNO_3:$HClO_4$ in the ratio 2:1) was added. After leaving for while, the flask was heated at a temperature slowly raised to 200°C. Heating was momentarily stopped when the dense white fumes of $HClO_4$ occurred.

The contents of the flask were boiled until they became clean and colorless. Elements like N, P, K, and S were determined from the digest.

3.13.4.3 Digestion of plant samples with sulphuric acid

An amount of 100 mg oven dry, ground samples was taken in a 100 ml Kjeldhal flask. Into the flask, 1.0 g catalyst mixture (K_2SO_4:$CuSO_4.5H_2O$: Se =10:1:0.1), 2 ml 30% H_2O_2 and 3ml conc. H_2SO_4 were added. The flask was swirled and allowed to stand for about 10 minutes, followed by heating at 200°C. Heating was continued until the digest was clear and colorless. After cooling, the contents were taken into a 100 ml volumetric flask and the volume was made with distilled water. This digestion was used for N determination exclusively.

3.13.4.4 Determination of elements

3.13.4.4.1 Available Nitrogen content (N)

Total N of the digest was determined by Microkjeldal method where seed was digested with 30% H_2O_2, conc. H_2SO_4 and catalyst mixture ($K_2O_{4,}$ $CuSO_{4.}$ $5H_2O$ Seed powder in the ratio of 100:10:1). Nitrogen in the digest was estimated by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01 N H_2SO_4 (Bremner and Mulvancy, 1982).

3.13.4.4.2 Available Phosphorus content (P)

Available P was extracted from the seed sample by shaking with 0.5 M $NaHCO_3$ solution of p^H 8.5 (Olsen *et al*., 1982). The P in the extract was then determined blue color using $SnCl_2$ reduction of phosphomolybdate complex. The absorbance of the molybdophosphate blue color was measured at 660 nm wave length by spectrometer and available P was calculated with the help of standard curve.

3.13.4.4.3 Available Potassium content (K)

Exchangeable K was determined by 1 N NH_4OAC (p^H 7.0) extract of seed by using flame photometer (Black, 1965).

3.13.4.4.4 Available Sulphur content (S)

Available S in the seed sample was determined by extracting the soil samples with 0.15% $CaCl_2$ solution (Page *et al*., 1989). The S content in the extract was determined turbid metrically and the intensity of the turbid measured by spectrophotometer at 420 nm wave length.

3.14 Statistical analysis

The data obtained from experiment on various parameters were statistically analyzed in MSTAT–C computer program by split-plot design (Russel, 1986). The mean values for all the parameters were calculate and the analysis of variance for the characters was accomplished by Duncan's Multiple Range Test (DMRT) and the significance of difference between pair of means was tested by the Least Significant Differences (LSD) test at 5 % levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to investigate the effect of different doses of Zn and B on the aspect of morpho–physiological, growth and yield attributing of blackgram *viz.* BARI Mash–3. The singly or interaction effect between Zn and B were noticeable from the presented data. The analysis of variance and their corresponding degrees of freedom were present in Appendices IV and XV. The mean values of these parameters have been presented in tables 1 to 24 and figures 1 to 18. The results of the present study have been presented and detailed discussion on the presented results with possible interpretations is given in this chapter under the following headings.

4.1 Effect of different doses of Zn and/or B on morpho–physiological characters

4.1.1 Plant height

Effect of Zinc (Zn)

Plant height is a key yield contributing characteristic which was also directly related with straw yield. Incase of the tallest plant ensure the greater yield of straw. Plant height data were recorded at four stages *viz.*, 20, 35, 50 and 65 days after sowing (DAS) during the study period. Plant height data were obtained by the effect of different doses of Zn. Analysis of variance data was also presented in Appendix IV. The enlargement of plant showed significant variation ($P<0.01$) regarding to plant height due to the effect of different doses of Zn at different DAS (Appendix IV and Fig. 1). From the Fig. 1, it was found that the Zn @ 2.5 kg ha^{-1} recorded the tallest plant (28.02, 45.91, 49.67 and 52.28 cm) at 20, 35, 50 and 65 DAS, respectively while Zn @ 1.25 kg ha^{-1} observed the statistically similar tallest plant at 20 DAS (27.73 cm). At these stages, the shortest plant (24.96, 37.01, 41.33 and 45.33 cm, respectively) was noticed from the control treatment. These results indicated that the Zn @ 2.5 kg ha^{-1} had highly efficient for better growth in case of the treatment increase the soil nutrient and moisture which was helped the proper growth of black gram over other treatments. Quddus *et al*. (2011) also found that Zn level 1.5 kg ha^{-1} recorded the highest plant height of 47.8 and 44.0 cm than other Zn levels at 2008 and 09, respectively. The findings of Ashok *et al*. (2010) reported the similar observation where they also found significant variation in plant height of black gram by the Zn application. Similarly, Sharma *et al*. (2010) reported that the treatment with RDF+$ZnSo_4$ 15 kg ha^{-1} recoded significantly higher plant height (196.10 cm) while Zn was applied as a form of $ZnSo_4$.

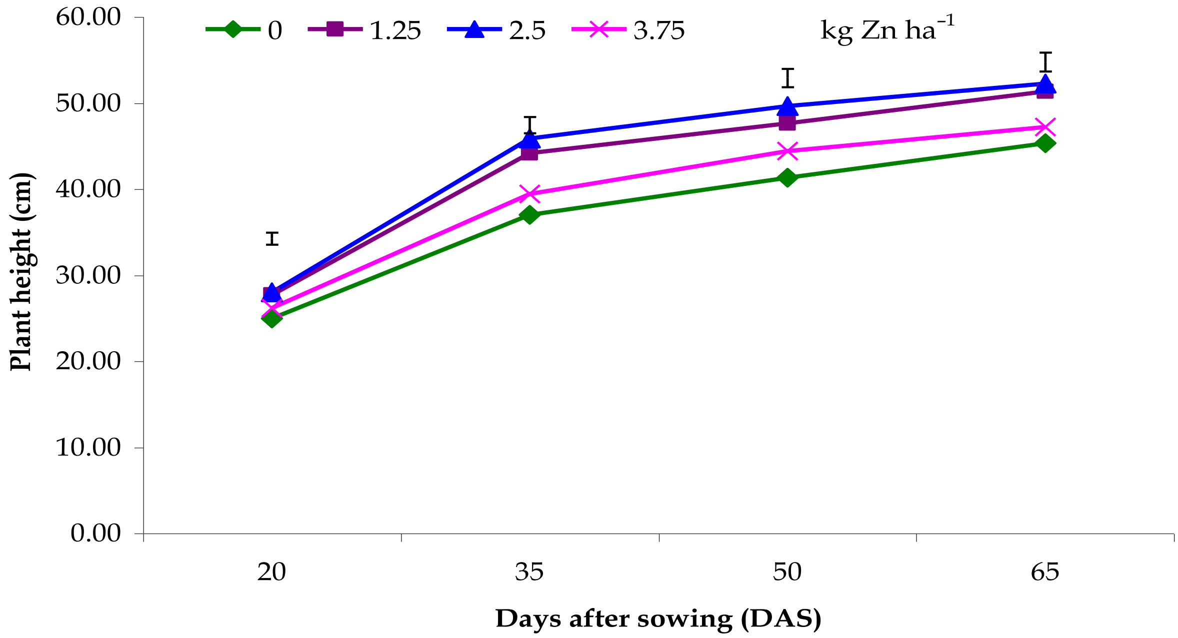

Fig. 1. Effect of Zinc (Zn) fertilizer on plant height of blackgram at different days after sowing. Vertical bar represents SE value

Effect of Boron (B)

Application of various doses of B was significantly influenced on plant height at 20, 35, 50 and 65 DAS (Appendix IV and Fig. 2). Among the doses of B fertilizer, B @ 1.5 kg ha^{-1} showed the tallest plant (28.87, 45.18, 48.58 and 52.00 cm) at 20, 35, 50 and 65 DAS, respectively which was statistically differed from other doses of B. In contrast, the shortest plant (25.01, 38.20, 41.67 and 46.32 cm) was recorded from the control treatment at these stages, respectively. These results indicated that, plant height was gradually increased due to the increase of B doses up to 1.5 kg ha^{-1}. The increasing in plant height may be familiar to 1.5 kg B and it was also more efficient to increase the soil properties which was helped the proper growth of black gram plant.

Significant increase in plant height induced by different doses of B was observed in mungbean (Quddus *et al*., 2011). They reported that B significantly influenced on plant height where 1.0 kg ha^{-1} B noticed the highest plant height. Kaisher *et al*. (2010) also found significant variation in plant height where the tallest plant was in 5 kg B ha^{-1} and the shortest from control. Similarly, Vishwakarma *et al*. (2008); Singaravel *et al*. (2006) also found significant variation in groundnut with application of borax as soil application.

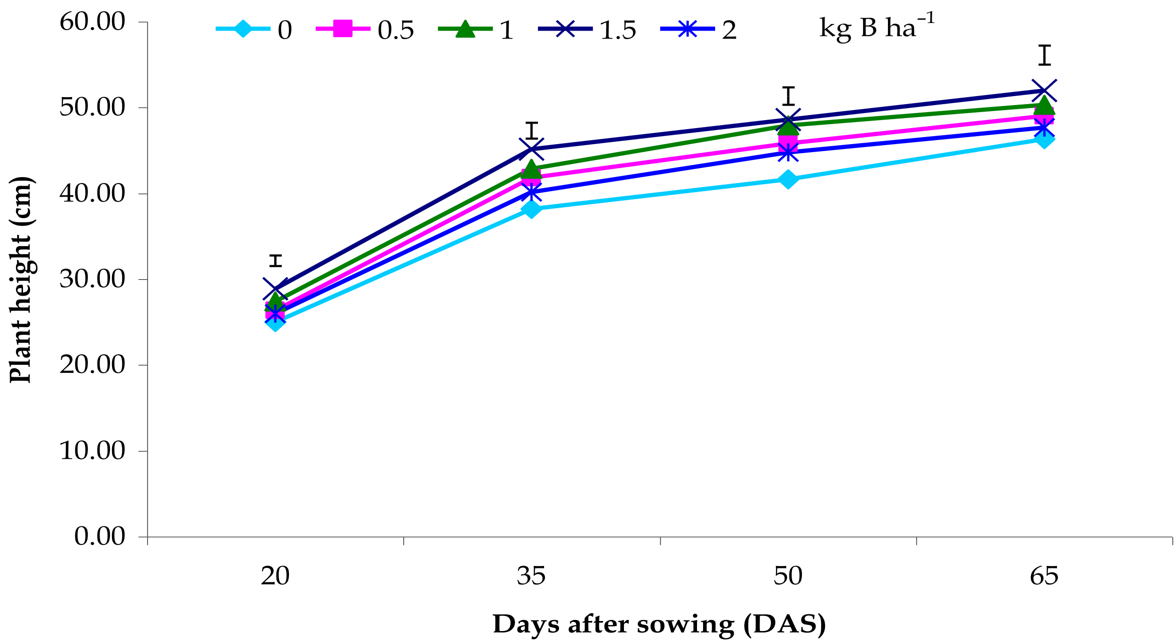

Fig. 2. Effect of Boron (B) fertilizer on plant height of black gram at different days after sowing. Vertical bar represents SE value

Interaction effect between Zn and B

Interaction effect between Zn and B fertilizers showed significant variation on plant height at different DAS (Appendix IV and Table 1). Among the interaction treatments, the tallest plant (31.27 cm) was noticed in treatment combination of $Zn_{1.25} \times B_{1.5}$ which was statistically differed from other interactions at 20 DAS. In contrast, the treatment combinations of $Zn_{2.5}$ and $B_{1.5}$ produced significantly the tallest plant (49.33, 53.75 and 55.31 cm) at 35, 50 and 65 DAS, respectively.

Whereas treatment combinations of $Zn_{2.5}$ and $B_{1.0}$ showed the statistically identical plant height (53.13 cm) at 50 DAS and $Zn_{1.25}×B_{1.5}$ also recorded the

Table 1. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on plant height of black gram at different days after sowing

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Plant height (cm) at different DAS			
		20	35	50	65
0	0	23.50 k	34.60 k	38.70 l	43.03 n
0	0.5	24.53 j	36.40 hi	41.40 jk	44.73 m
0	1.0	25.60 i	37.10 h	42.23 i	46.10 kl
0	1.5	26.97 e–g	41.03 f	43.17 gh	48.30 g
0	2.0	24.20 jk	35.93 ij	41.17 k	44.47 m
1.25	0	26.20 g–i	40.62 f	43.60 g	48.10 gh
1.25	0.5	26.63 f–h	45.68 c	47.20 d	51.47 d
1.25	1.0	28.30 cd	46.12 c	50.20 b	53.40 c
1.25	1.5	31.27 a	47.58 b	50.87 b	54.77 ab
1.25	2.0	26.27 f–i	41.12 f	46.33 e	49.23 f
2.5	0	26.37 f–i	42.30 e	42.10 ij	48.41 g
2.5	0.5	27.82 de	46.10 c	50.27 b	52.91 c
2.5	1.0	28.71 c	47.20 b	53.13 a	54.18 b
2.5	1.5	29.58 b	49.33 a	53.75 a	55.31 a
2.5	2.0	27.63 de	44.63 d	49.10 c	50.61 e
3.75	0	23.97 jk	35.27 jk	42.28 i	45.74 l
3.75	0.5	26.43 f–i	39.07 g	44.55 f	46.91 ij
3.75	1.0	27.17 ef	41.13 f	46.22 e	47.51 hi
3.75	1.5	27.67 de	42.77 e	46.55 de	49.61 f
3.75	2.0	25.83 hi	38.90 g	42.58 hi	46.51 jk
SE value		**0.2807**	**0.3261**	**0.2486**	**0.2379**
Significance level		**	**	**	**
CV (%)		**6.83**	**5.36**	**5.94**	**3.84**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

statistically close result (54.77 cm) at 65 DAS. On the other hand, the shortest plant of black gram (23.50, 34.60, 38.70 and 43.03 cm) was taken from the control treatment ($Zn_0×B_0$) which was closely followed by the treatment combinations of $Zn_{3.75}$ and B_0 at 20 and 35 DAS (23.97 and 35.27 cm, respectively). From the above observation, it was found that the plant height was increased with the advancement of studied period and also the increasing rate of Zn and B up to 2.5 and 1.5 kg ha^{-1}, respectively. Similar findings were also observed by Tekale *et al*. (2009) who examine the impact of B, Zn and IAA on pigeon pea variety Asha and ICPL81–119 where they found that the treatment T_4 (IAA + B + Zn at both FL and PI stages) showed higher increase in plant height which was mainly attributed due to higher shoot growth through cell elongation, cell differentiation and apical dominance promoted by IAA in addition with Zn and B.

4.1.2 Number of leaves plant^{-1}

Effect of Zinc (Zn)

Analysis of variance data on leaves number plant^{-1} was significantly influenced by the effect of Zn at different DAS except 65 DAS (Appendix V and Table 2). From the Table 2, it was found that the Zn @ 2.5 kg ha^{-1} recorded the maximum number of leaves plant^{-1} (18.28, 48.32 and 112.10) at 20, 35 and 50 DAS, respectively while Zn @ 1.25 kg ha^{-1} observed the statistically close at 20 and 50 DAS (47.95 and 111.60, respectively) and Zn @ 3.75 at 50 DAS (111.4) whereas Zn @ 1.25 and 3.75 were statistically identical at 50 DAS. At these stages, the minimum number of leaves plant^{-1} (17.27, 47.33 and 110.90, respectively) was observed in control treatment. Leaves production plant^{-1} at 65 DAS were statistically identical among the different doses of Zn. However, Table 2 also revealed that leaf production of black gram rapidly increased up to 50 DAS and thereafter it increased very slowly at 65 DAS which might be due to the leaf number decrease at this stage due to its maturity and the several leaves were fall down from the plant at harvest.

Table 2. Effect of Zinc (Zn) fertilizers on number of leaves plant^{-1} at different days after sowing

Different levels of Zn (kg ha^{-1})	Number of leaves plant^{-1} at different DAS			
	20	35	50	65
0	17.27 d	47.33 c	110.90 b	116.10 a
1.25	17.92 b	47.95 ab	111.60 ab	116.70 a
2.5	18.28 a	48.32 a	112.10 a	117.30 a
3.75	17.55 c	47.59 bc	111.40 ab	116.40 a
SE value	**0.0157**	**0.1769**	**0.2896**	**0.3834**
Significance levels	**	**	**	**
CV (%)	**3.34**	**5.43**	**4.10**	**3.27**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Effect of Boron (B)

Effect of different doses of B had also significant in respect of leaf production at 20, 35, 50 and 65 DAS (Appendix V and Table 3). Among the B doses, leaves plant^{-1} had maximum (18.42, 48.63, 112.80 and 117.80) in B @ 1.5 kg ha^{-1} while rest of the B doses except control were produced statistically identical leaves production at 65 DAS.

Table 3. Effect of Boron (B) fertilizers on number of leaves plant^{-1} at different days after sowing

Different levels of B (kg ha^{-1})	Number of leaves plant^{-1} at different DAS			
	20	**35**	**50**	**65**
0	16.90 e	46.90 c	108.60 c	114.30 b
0.5	17.78 c	47.78 b	112.00 ab	117.00 a
1.0	18.10 b	48.10 ab	112.30 ab	117.30 a
1.5	18.42 a	48.63 a	112.80 a	117.80 a
2.0	17.57 d	47.57 b	111.80 b	116.80 a
SE value	**0.0175**	**0.1978**	**0.3238**	**0.4287**
Significance levels	**	**	*	*
CV (%)	**3.34**	**5.43**	**4.10**	**3.27**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Similarly, control treatment showed the minimum leaves plant^{-1} (16.90, 46.90, 108 and 114.30) at 20, 35, 50 and 65 DAS, respectively which was statistically differed from other doses of B. The variation in leaf production by the application of B was found for the variation in adequate nutrient compilation from the soil.

Interaction effect between Zn and B

A significant variation was also found due to the interaction effect between Zn and B fertilizers at different DAS on leaf production plant^{-1} in this study (Appendix V and Table 4).

Table 4. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on number of leaves plant^{-1} at different days after sowing

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Number of leaves plant^{-1} at different DAS			
		20	35	50	65
0	0	16.53 l	46.53 f	107.70 b	113.70 e
0	0.5	17.27 h	47.27 c–f	111.50a	116.50 a–e
0	1.0	17.67 f	47.67 b–f	111.90 a	116.90 a–c
0	1.5	17.87 e	48.20 a–e	112.30 a	117.30 ab
0	2.0	17.00 j	47.00 ef	111.30 a	116.30 a–e
1.25	0	17.13 i	47.13 d–f	108.40 b	114.30 c–e
1.25	0.5	17.87 e	47.87 b–f	112.10 a	117.10 a–c
1.25	1.0	18.33 c	48.33 a–e	112.50 a	117.50 ab
1.25	1.5	18.60 b	48.73 ab	112.90 a	117.90 ab
1.25	2.0	17.67 f	47.67 b–f	111.90 a	116.90 a–c
2.5	0	17.27 h	47.27 c–f	109.30 b	115.30 b–e
2.5	0.5	18.40 c	48.40 a–d	112.60 a	117.60 ab
2.5	1.0	18.53 b	48.53 a–c	112.70 a	117.70 ab
2.5	1.5	19.00 a	49.20 a	113.40 a	118.40 a
2.5	2.0	18.20 d	48.20 a–e	112.40 a	117.40 ab
3.75	0	16.67 k	46.67 f	108.90 b	113.90 de
3.75	0.5	17.60 f	47.60 b–f	111.80 a	116.80 a–c
3.75	1.0	17.87 e	47.87 b–f	112.10 a	117.10 a–c
3.75	1.5	18.20 d	48.40 a–d	112.60 a	117.60 ab
3.75	2.0	17.40 g	47.40 b–f	111.60 a	116.60 a–d
SE value		**0.0350**	**0.3955**	**0.6477**	**0.8573**
Significance level		**	*	*	*
CV (%)		**3.34**	**5.43**	**4.10**	**3.27**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

At 20 DAS, interaction effect between Zn @ 2.5 and B @ 1.5 kg ha^{-1} showed the maximum leaves plant^{-1} (19.00) while the minimum number of leaves plant^{-1} (16.53) was recorded from the treatment combination of without Zn and B. Similarly, interaction effect of Zn @ 2.5 and B @ 1.5 kg ha^{-1} further recorded the maximum leaves plant^{-1} (49.20 and 118.40) at 35 and 65 DAS, respectively whereas the leaf production of other interactions was not statistically identical at 35 and 65 DAS but it was statistically close among the maximum treatment combinations at 35 and 65 DAS. The minimum number of leaves plant^{-1} (46.53 and 113.70) was recorded from the control treatment of both fertilizers and it was statistically identical with the interaction effect between Zn @ 3.75 kg ha^{-1} and without B at 35 DAS (46.67). At 50 DAS, all the treatment combinations were produced statistically identical maximum leaf production plant^{-1} at 50 DAS except all the Zn doses in combination of without B where they were also produced statistically identical minimum leaf production. However, maximum number of leaves plant^{-1} (113.40) was found in combinations of Zn @ 2.5 and B @ 1.5 kg ha^{-1} and the minimum (107.70) in both control combination at 50 DAS.

4.1.3 Number of branches plant^{-1}

Effect of Zinc (Zn)

Analysis of variance data on number of branches plant^{-1} was presented (Appendix VI and Fig. 3) indicated significant difference (P<0.01) among the effect of Zn at different DAS (Fig. 3). The maximum number of branches plant^{-1} (3.11, 5.12, 4.73 and 5.71) was recorded from the treatment $Zn_{2.5}$ at 20, 35, 55 and 65 DAS, respectively whereas all the treatments were statistically differed from other treatments at all the data recording stages. On the other hand, the minimum number of branches plant^{-1} (1.92, 3.82, 4.06 and 4.24) was recorded in without Zn treatment at these stages, respectively. The variation in branch production was found for the variation in adequate nutrient compilation from the soil by the application variation of Zn.

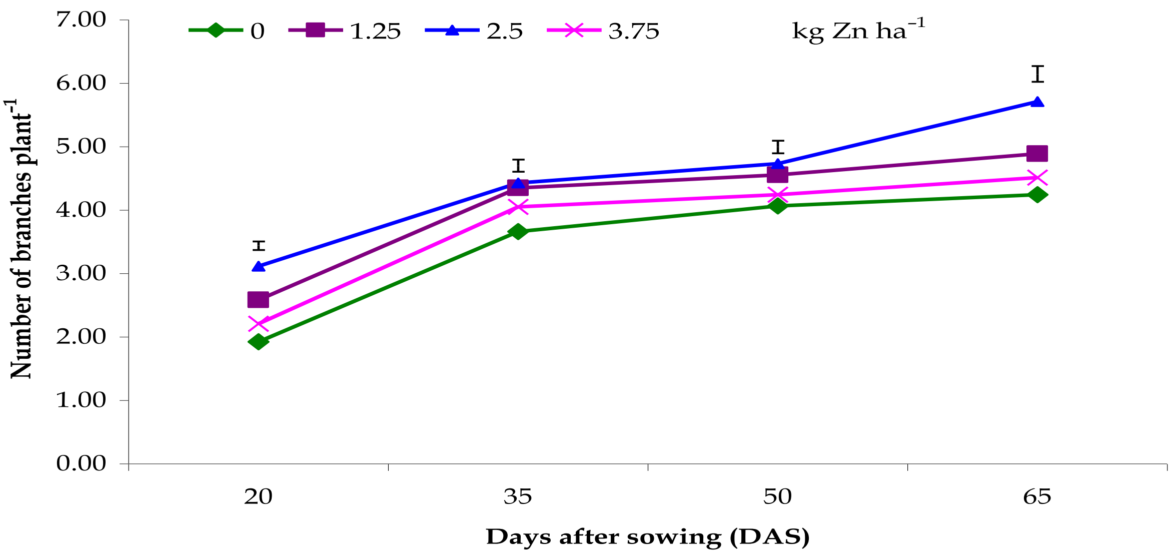

Fig. 3. Effect of Zinc (Zn) fertilizer on number of branches plant^{-1} of black gram at different days after sowing. Vertical bar represents SE value

A significant variation in branch production among the Zn application were found by Khorgamy and Farnia (2009) who reported that the variety chickpea (*Cicer arietinum*) had a significant effect on number of main branch by Zn fertilizer application. While Zn @ 20 kg ha^{-1} produced higher number of branches plant^{-1} than other treatments.

Effect of Boron (B)

Boron application at different doses had significant on branch production at different DAS (Appendix VI and Fig. 4). As a result, the maximum number of branches plant^{-1} (3.25, 5.30, 5.14 and 5.86) was obtained from the Zn @ 2.5 kg ha^{-1} while without B treatment recorded the minimum (1.79, 3.80, 3.61 and 4.02) at 20, 35, 50 and 65 DAS, respectively. Kaisher *et al*. (2010) stated that application of B increases number of branches plant^{-1} maximum was in 5 kg B ha^{-1}.

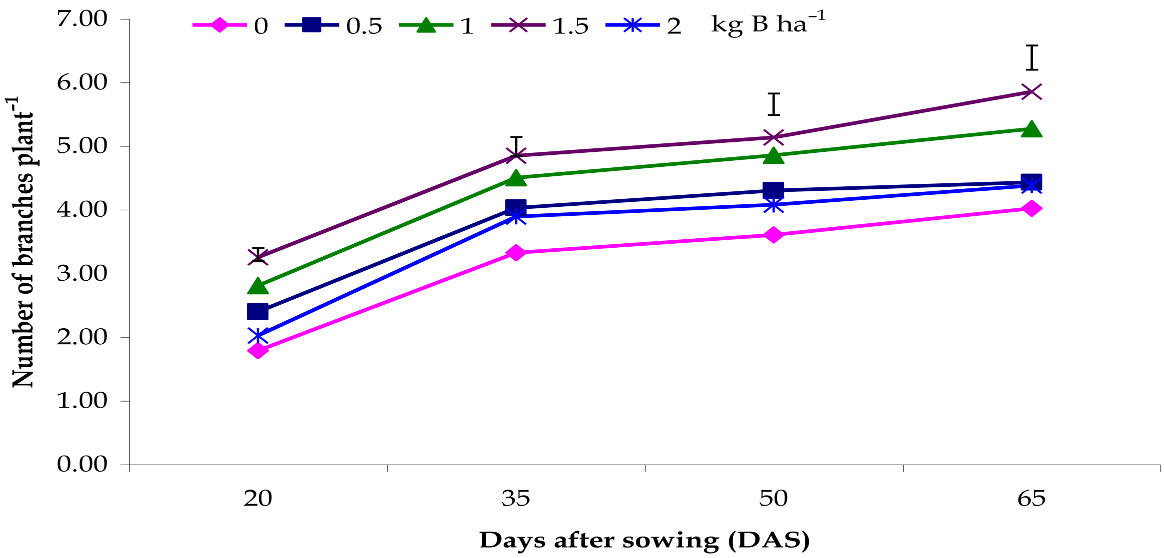

Fig. 4. Effect of Boron (B) fertilizer on number of branches plant^{-1} of black gram at different days after sowing. Vertical bar represents SE value

Interaction effect between Zn and B

Interaction effect of Zn and B had significant regarding to branch production of blackgram at different DAS (Appendix VI and Table 5). Among the interaction treatments, the maximum number of branches plant^{-1} (3.94, 6.00, 5.55 and 7.11) was exhibited from the treatment combination of $Zn_{2.50}×B_{1.5}$ which was statistically differed from other interactions among the studied period such as 20, 35, 50 and 65 DAS, respectively.

Table 5. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on number of branches plant^{-1} at different days after sowing

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Number of branches plant^{-1} at different DAS			
		20	35	50	65
0	0	1.33 n	3.02 i	3.44 m	3.66 j
0	0.5	1.78 l	3.50 g	3.99 ij	4.10 hi
0	1.0	2.38 h	3.96 f	4.44 f–h	4.55 f
0	1.5	2.56 g	4.26 e	4.77 c–e	4.99 e
0	2.0	1.55 m	3.56 g	3.66 k–m	3.88 ij
1.25	0	1.87 kl	3.26 h	3.66 k–m	4.11 hi
1.25	0.5	2.36 h	4.24 e	4.44 f–h	4.55 f
1.25	1.0	2.97 e	4.79 c	4.99 c	5.33 d
1.25	1.5	3.77 b	5.16 b	5.33 b	5.99 c
1.25	2.0	1.92 k	4.26 e	4.33 gh	4.44 fg
2.5	0	2.30 hi	3.56 g	3.77 j–l	4.55 f
2.5	0.5	3.22 d	4.26 e	4.55 e–g	5.55 d
2.5	1.0	3.54 c	4.82 bc	5.33 b	6.33 b
2.5	1.5	3.94 a	5.26 a	5.55 a	7.10 a
2.5	2.0	2.55 g	4.18 ef	4.44 f–h	4.99 e
3.75	0	1.64 m	3.44 gh	3.55 lm	3.77 j
3.75	0.5	2.22 i	4.10 ef	4.21 hi	4.33 f–h
3.75	1.0	2.35 h	4.44 d	4.66 d–f	4.88 e
3.75	1.5	2.73 f	4.69 c	4.88 cd	5.33 d
3.75	2.0	2.08 j	3.56 g	3.88 jk	4.22 gh
SE value		**0.0407**	**0.0306**	**0.0855**	**0.0771**
Significance level		**	**	*	**
CV (%)		**4.87**	**2.19**	**3.04**	**3.30**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

In contrast, interaction effect of control treatment of both fertilizers recorded the minimum branches plant^{-1} (1.33, 3.22, 3.44 and 3.66) at 20, 35, 50 and 65 DAS, respectively which was also statistically different from other interactions at 20, 35 and 65 DAS but at 50 DAS it was statistically identical with the interaction effect between Zn @ 3.75 kg ha^{-1} with control treatment of B (3.77). Significant variation in branch production was also obtained by Tekale *et al*. (2009) who examine the impact of B, Zn and IAA while number of branches plant^{-1} revealed that treatment T_4 (IAA + B + Zn at both FL and PI stages) (18.32 and 21.27 at 50% podding and maturity stages respectively) gave the maximum value as compared to other treatments. These might be due to promotion of bud and branch development by the auxins whereas B and Zn application ultimately increased the availability of other nutrients. Sharma *et al*. (2010)

also found that the soil application with RDF+$ZnSo_4$ 15 kg ha^{-1} recorded significantly higher number of primary branches (14.30) and secondary branches (10.10).

4.1.4 Length of root

Effect of Zinc (Zn)

Length of root data was also recorded at 20, 35, 50 and 65 DAS whereas all the studied period data were significant due to the effect of Zn application (Appendix VII and Table 6). Among the Zn doses, Zn @ 2.5 kg ha^{-1} recorded the longest root (3.58, 5.39, 7.20 and 9.63 cm) while without Zn noticed the shortest root (3.16, 4.79, 6.52 and 9.01 cm) at 20, 35, 50 and 65 DAS, respectively (Table 6).

Table 6. Effect of Zinc (Zn) fertilizers on length of root at different days after sowing

Different levels of Zn (kg ha^{-1})	Length of root (cm) at different DAS			
	20	35	50	65
0	3.15 d	4.78 d	6.52 d	9.01 d
1.25	3.40 b	4.96 c	6.78 c	9.21 c
2.5	3.57 a	5.38 a	7.19 a	9.62 a
3.75	3.30 c	5.09 b	6.91 b	9.34 b
SE value	**0.0019**	**0.0099**	**0.0298**	**0.0168**
Significance levels	**	**	**	**
CV (%)	**3.22**	**5.76**	**6.68**	**2.70**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Table 6 also indicated that all the doses of Zn were statistically different with each other at 5% level. Length of root also found significant difference among the application of Zn by the findings of Ashok *et al*. (2010). They found that the Zn effected the plant growth of blackgram. Where the root length of control plants was 6.2, cm in blackgram whereas root length was 5.9 cm in Zn treated blackgram.

Effect of Boron (B)

A highly significant variation was also obtained by the effect of B application on root length at different DAS (Appendix VII and Table 7). Among the B doses, B @ 1.5 gave the longest root (3.60, 5.29, 7.09 and 9.57 cm) at 20, 35, 50 and 65 DAS, respectively which was statistically differed from other treatments at 20, 35 and 65

DAS but statistically identical with B @ 1.0 kg ha^{-1} at 50 DAS (7.04 cm). On the other hand, without B recorded the shortest root both at 20 DAS (3.01 cm), 35 DAS (4.54 cm), 50 DAS (6.34 cm) and 65 DAS (8.84 cm) whereas they were also statistically differed among other treatments (Table 7). These results revealed that the B @ 1.5 kg ha^{-1} produced the longest root of blackgram at all the data recording stages. Length of root increased significantly with the increasing growing period. These results were also found due to the 1.5 kg B ha^{-1} provided the soil fertility, enhance the soil properties and properly manage the imbalance pH and moisture which ultimately increase the root length of blackgram.

Table 7. Effect of Boron (B) fertilizers on length of root at different days after sowing

Different levels of B (kg ha^{-1})	Length of root (cm) at different DAS			
	20	35	50	65
0	3.00 e	4.53 e	6.33 c	8.83 e
0.5	3.40 c	5.13 c	6.93 b	9.34 c
1.0	3.44 b	5.24 b	7.03 a	9.44 b
1.5	3.60 a	5.29 a	7.08 a	9.57 a
2.0	3.35 d	5.07 d	6.87 b	9.28 d
SE value	**0.0021**	**0.0110**	**0.0398**	**0.0188**
Significance levels	**	**	**	**
CV (%)	**3.22**	**5.76**	**6.68**	**2.70**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Interaction effect between Zn and B

Interaction effect between Zn and B was significantly influenced on root length at different DAS (Appendix VII and Table 8). Among the data recording stages *viz.*, 20, 35, 50 and 65 DAS, the longest root (3.81, 5.64, 7.51 and 9.92 cm, respectively) was found from the interaction effect between Zn @ 2.5 and B @ 1.5 kg ha^{-1} which was statistically differed among other interaction at every data recording stages.

However, interaction effect of Zn @ 2.5 and B @ 1.0 kg ha^{-1} showed the statistically close root length (7.35 cm) at 50 DAS. On the other hand, the shortest root (2.79, 4.27, 6.08 and 8.57 cm) was found from the interaction effect of both control level.

Table 8. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on length of root at different days after sowing

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Length of root (cm) at different DAS			
		20	**35**	**50**	**65**
0	0	2.79 n	4.27 m	6.07 j	8.57 k
0	0.5	3.20 jk	4.85 i	6.65 h	9.06 hi
0	1.0	3.24 j	4.98 h	6.74 gh	9.16 gh
0	1.5	3.40 gh	5.05 g	6.56 h	9.27 fg
0	2.0	3.15 k	4.76 j	6.56 h	8.97 i
1.25	0	3.04 l	4.46 l	6.26 i	8.70 j
1.25	0.5	3.45 fg	5.06 g	6.86 e–g	9.27 fg
1.25	1.0	3.49 f	5.16 f	6.96 def	9.373 ef
1.25	1.5	3.64 bc	5.14 f	7.06 c–e	9.47 de
1.25	2.0	3.40 gh	4.97 h	6.77 f–h	9.18 gh
2.5	0	3.25 j	4.86 i	6.66 gh	9.17 gh
2.5	0.5	3.60 cd	5.45 c	7.25 bc	9.66 bc
2.5	1.0	3.66 b	5.55 b	7.35 ab	9.76 b
2.5	1.5	3.80 a	5.64 a	7.51 a	9.92 a
2.5	2.0	3.56 de	5.41 c	7.21 bc	9.62 c
3.75	0	2.93 m	4.55 k	6.35 i	8.85 j
3.75	0.5	3.35 hi	5.17 f	6.97 d–f	9.38 ef
3.75	1.0	3.39 h	5.26 e	7.08 cd	9.49 d
3.75	1.5	3.54 e	5.33 d	7.22 bc	9.63 c
3.75	2.0	3.30 i	5.16 f	6.96 def	9.37 ef
SE value		**0.0042**	**0.0221**	**0.0666**	**0.0377**
Significance level		**	**	**	**
CV (%)		**3.22**	**5.76**	**6.68**	**2.70**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

These results revealed that the application of Zn and B improve the soil fertility and they manipulate crop productivity. Such as results were also agreed with the findings of Salam (2004) reported that B increased the plant growth, root length and root nodule numbers of bean.

4.2 Effect of Zn and/or B on growth characters

4.2.1 Leaf area index (LAI)

Effect of Zinc (Zn)

Leaf area index indicated the growth rate of leaf and the data on LAI was recorded at four stages during study period. Analysis of variance data regarding to LAI was significantly influenced by the effect of different doses of Zn fertilizer at different DAS (Appendix VIII and Table 9). Among the different doses of Zn, LAI had higher (0.75, 1.22, 1.77 and 1.45) in Zn @ 2.5 kg ha^{-1} at 20, 35, 50 and 65 DAS, respectively which was statistically differed from other Zn treatments but it was statistically close to Zn @ 1.5 kg ha^{-1} at those stages (0.73, 1.20, 1.75 and 1.46, respectively). Similarly, without Zn gave the lowest LAI (0.70, 1.17, 1.72 and 1.43) at 20, 35m 50 and 65 DAS, respectively which was also closely followed by the Zn application @ 3.75 kg ha^{-1} at 20, 35, 50 and 65 DAS (0.71, 1.18, 1.74 and 1.45, respectively).

Table 9. Effect of Zinc (Zn) fertilizers on leaf area index at different days after sowing

Different levels of Zn (kg ha^{-1})	Leaf area index at different DAS			
	20	**35**	**50**	**65**
0	0.70 c	1.17 c	1.73 c	1.44 c
1.25	0.73 ab	1.20 ab	1.76 ab	1.46 ab
2.5	0.76 a	1.22 a	1.78 a	1.49 a
3.75	0.72 bc	1.19 bc	1.74 bc	1.45 bc
SE value	**0.0012**	**0.0011**	**0.0012**	**0.0013**
Significance levels	**	**	**	**
CV (%)	**5.66**	**3.35**	**4.26**	**3.33**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

These results indicated that the LAI of black gram significantly increased up to 50 DAS and thereafter it decreased. Which might found due to the leaf fall from the plant at maturity stage which ultimately reduces the leaf from plant and it decreased the LAI of blac kgram.

Effect of Boron (B)

Application of different doses of B was also showed significant variation on LAI at different DAS (Appendix VIII and Table 10). From the Table 7, it was found that the B @ 1.5 kg ha^{-1} recorded the highest LAI (0.78, 1.25, 1.82 and 1.52) and without B obtained the lowest LAI (0.68, 1.13, 1.65 and 1.38) at 20, 35, 50 and 65 DAS, respectively. Rest of the B doses was statistically identical to produced LAI of black gram at every data recording stages. Salam (2004) reported that B increased the plant growth, leaf area index, and root length and root nodules of bean.

Table 10. Effect of Boron (B) fertilizers on leaf area index at different days after sowing

Different levels of B (kg ha^{-1})	**Leaf area index at different DAS**			
	20	**35**	**50**	**65**
0	0.67 c	1.14 c	1.65 c	1.39 c
0.5	0.72 b	1.20 b	1.76 b	1.47 b
1.0	0.74 b	1.21 b	1.78 b	1.48 b
1.5	0.78 a	1.25 a	1.82 a	1.52 a
2.0	0.71 b	1.20 b	1.75 b	1.46 b
SE value	**0.0014**	**0.0012**	**0.0013**	**0.0014**
Significance levels	**	**	**	**
CV (%)	**5.66**	**3.35**	**4.26**	**3.33**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Interaction effect between Zn and B

Leaf area index of black gram in this study had significant due to the interaction effect of Zn and B fertilizer doses at different DAS (Appendix VIII and Table 11). Among the interaction effect, interaction effect between Zn @ 2.5 and B @ 1.5 kg ha^{-1} recorded the higher LAI (0.80, 1.28, 1.84 and 1.54) at 20, 35, 50 and 65 DAS, respectively. Whereas statistically close LAI (0.77, 1.25, 1.81 and 1.52, respectively) were taken from the interaction effect between Zn @ 1.25 and B @ 1.5 kg ha^{-1}.

Table 11. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on leaf area index at different days after sowing

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Leaf area index at different DAS			
		20	35	50	65
0	0	0.65 h	1.11 h	1.63 g	1.36 i
0	0.5	0.70 d–h	1.17 d–g	1.74 d-f	1.44 d–g
0	1.0	0.72 b–g	1.19 b–f	1.76 b–e	1.46 b–f
0	1.5	0.76 a–d	1.23 a–d	1.79 a–d	1.50 a–d
0	2.0	0.69 e–h	1.16 e–h	1.73 ef	1.43 e–h
1.25	0	0.68 f–h	1.15 f–h	1.66 g	1.39 g–i
1.25	0.5	0.73 b–f	1.20 b–f	1.77 b–e	1.47 b–f
1.25	1.0	0.74 b–f	1.22 b–e	1.78 b–e	1.49 b–e
1.25	1.5	0.78 ab	1.25 ab	1.82 ab	1.52 ab
1.25	2.0	0.72 b–g	1.19 b–f	1.76 b–e	1.47 b–f
2.5	0	0.70 d–h	1.17 e–h	1.68 fg	1.42 f–i
2.5	0.5	0.75 a–e	1.22 a–e	1.79 a–e	1.49 a–e
2.5	1.0	0.77 a–c	1.24 a–c	1.80 a–c	1.51 a–c
2.5	1.5	0.81 a	1.28 a	1.84 a	1.55 a
2.5	2.0	0.74 b–f	1.21 b–e	1.78 b–e	1.48 b–e
3.75	0	0.67 gh	1.13 gh	1.64 g	1.38 hi
3.75	0.5	0.72 c–g	1.19 c–f	1.76 c–e	1.46 c–f
3.75	1.0	0.73 b–f	1.20 b–f	1.77 b–e	1.47 b–f
3.75	1.5	0.76 a–c	1.24 a–c	1.80 a–c	1.51 a–c
3.75	2.0	0.72 c–h	1.18 c–g	1.75 c–e	1.45 c–g
SE value		**0.0028**	**0.0024**	**0.0026**	**0.0028**
Significance level		*	*	*	*
CV (%)		**5.66**	**3.35**	**4.26**	**3.33**

*= Significant at 5% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

In contrast, the lowest LAI at those stages (0.65, 1.11, 1.63 and 1.36, respectively) were found from the interaction between both control treatment which was also statistically close to the interaction between Zn @ 3.75 and without B at 20 DAS (0.66), 35 DAS (1.13) and 65 DAS (1.37) but similar interaction treatment was statistically identical at 50 DAS (1.64). From the above results investigation of LAI, it was found that the LAI increase from sowing period to 50 DAS and then it decreased at maturity (65 DAS) stage which might be found due to the leaf fall from the black gram plant at maturity. In case of the some leaf are turned yellow for its maturity and fall down from the plant which supported to decrease the LAI at harvest or maturity stage.

4.2.2 Total dry matter (TDM)

Effect of Zinc (Zn)

TDM of black gram data were recorded at 5, 20, 35, 50 and 65 DAS (five stages) under the observation of different levels of Zn which have been presented in Table 12. Analysis of variance (mean square) data was also showed in Appendix IX whereas it was recorded that the TDM was significantly affected during the study. The higher TDM of black gram in the present study was found from the application of Zn @ 2.5 kg ha^{-1} at all the data recording stages than other application levels of Zn. As a result, the higher TDM (3.39, 43.11, 93.81, 249.90 and 379.50 g $plant^{-1}$) was taken in 2.50 kg ha^{-1} Zn at 5, 20, 35, 50 and 65 DAS, respectively which was statistically differed from other levels of Zn at every stagers. Similarly, without Zn treated plant of black gram recorded the lowest TDM (2.50, 27.61, 74.75, 224.70 and 349.10 g $plant^{-1}$) at those stages, respectively. TDM had higher in Zn @ 2.50 kg ha^{-1} in case of the maximum tallest plant, maximum number of leaves and branches $plant^{-1}$ were recorded under this treatment which ultimately make sure the higher TDM. Besides, the plant of black gram attain proper soil nutrient and moisture while it was treated by 2.5 kg ha^{-1} Zn treated plot than other levels. The results of TDM also indicated that the TDM of black gram was significantly increased with the advancement of study period and the higher TDM were achieved at 65 DAS (harvest or maturity stage) due to the plant height and branch production significantly increased up to maturity stages. This may be also possible incase of the proper soil nutrient, balance pH value and adjusted the N_2–fixation were achieved from the 2.5 kg ha^{-1} Zn than other B treatment which ensured the proper growth of black gram as well as higher weight of dry shoot.

Valenciano *et al*. (2011) reported that among the fertilizer application, Zn @ 241.0 g ha^{-1} produces the maximum total dry matter weight (14.97 g $plant^{-1}$) of chick pea.

Table 12. Effect of Zinc (Zn) fertilizers on total dry matter at different days after sowing

Different levels of Zn ($kg\ ha^{-1}$)	Total dry matter at different DAS				
	5	20	35	50	65
0	2.49 d	27.61 d	74.75 d	224.70 d	349.10 d
1.25	3.12 b	37.82 b	87.38 b	241.50 b	369.50 b
2.5	3.39 a	43.11 a	93.82 a	249.90 a	379.50 a
3.75	2.65 c	34.51 c	81.80 c	235.80 c	363.00 c
SE value	**0.0030**	**0.4977**	**0.2856**	**0.4647**	**0.2708**
Significance levels	**	**	**	**	**
CV (%)	**4.40**	**2.31**	**5.31**	**3.76**	**2.29**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Effect of Boron (B)

A significantly variation was also found due to the effect of different doses of B fertilizers on TDM at different DAS (Appendix IX and Table 13). From the Table 13, it was found that the application of B @ 1.5 kg ha^{-1} obtained the higher TDM (3.51, 44.10, 96.76, 242.40 and 386.00 g $plant^{-1}$) at 5, 20, 35, 50 and 65 DAS, respectively which was statistically differed from other B treatments. In contrast, without B treated plant gave the lowest TDM (1.46, 19.91, 64.96, 200.60 and 200.60 g $plant^{-1}$) at those stages, respectively which was also statistically differed from other treatments. Besides, all the B treatments at all stages were statistically differed with each other at 5% level. These results revealed that TDM data increase rapidly with the increasing sowing time and higher TDM was found under B @ 1.5 kg ha^{-1} in case of the tallest plant, higher number of leaves and branches were obtained under this treatment. This may be also possible incase of the proper soil nutrient, balance pH value and adjusted the N_2–fixation were achieved from the 1.5 kg ha^{-1} B than other B treatment which ensured the proper growth of black gram as well as higher weight of dry shoot. Valenciano *et al*. (2011) reported that B_1 (241.00 g ha^{-1}) had also showed greater performance on total dry matter weight (14.01 g $plant^{-1}$) of chickpea. Similarly, Valenciano *et al*. (2010) also found significant variation in TDM production by B (0 and 2 mg B pot^{-1}) application while the mature plants fertilized with B had a greater total dry matter production.

Table 13. Effect of Boron (B) fertilizers on total dry matter at different days after sowing

Different levels of B ($kg\ ha^{-1}$)	Total dry matter at different DAS				
	5	**20**	**35**	**50**	**65**
0	1.47 e	19.91 e	64.96 e	200.60 e	329.10 e
0.5	3.16 c	37.64 c	85.15 c	226.60 c	369.60 c
1.0	3.38 b	41.29 b	92.00 b	233.10 b	377.30 b
1.5	3.51 a	44.10 a	96.76 a	242.40 a	386.00 a
2.0	3.06 d	35.87 d	83.30 d	220.60 d	364.30d
SE value	**0.0033**	**0.5565**	**0.3196**	**0.5196**	**0.3027**
Significance levels	**	**	**	**	**
CV (%)	**4.40**	**2.31**	**5.31**	**3.76**	**2.29**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Interaction effect between Zn and B

Appendix IX indicated significant differences regarding to TDM due to the interaction effect between Zn and B fertilizers at different DAS which significant data was also presented in Table 14. The higher TDM (3.98, 51.78, 106.50, 272.90 and 403.60 g $plant^{-1}$) was found from the interaction effect between Zn @ 2.5 and B @ 1.5 kg ha^{-1} fertilizer at 5, 20, 35, 50 and 65 DAS, respectively which results were statistically differed from other interactions at all the data recording stages. On the other hand, the lowest TDM (1.11, 13.07, 57.45, 200.60 and 313.60 g $plant^{-1}$) was observed in interaction of $Zn_{2.5}\times B_{1.5}$ at those sages, respectively which was also statistically differed from other interactions during the study. Similarly, Valenciano *et al*. (2010) reported that the mature plants fertilized with Zn, with B and with Mo had a greater total dry matter production. Tekale *et al*. (2009) also found similar results where T_4 (IAA+ B +Zn at both FL and PI stages) produced higher total dry matter at all crop growth stages. The recommended NPK in combination with 25 kg $ZnSO_4$ ha^{-1}, 10 kg borax ha^{-1} and 10 t composted coir pith ha^{-1} gave the highest values for dry mater production at all growing stages of the crop which was found by Singaravel (2006).

Table 14. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on total dry matter at different days after sowing

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Total dry matter at different DAS				
		5	20	35	50	65
0	0	1.11 p	13.07 n	57.45 n	200.60 m	313.60 o
0	0.5	2.76 k	28.80 j	73.67 j	226.60 i	353.40 j
0	1.0	2.88 j	33.08 i	82.57 h	233.10 h	359.90 i
0	1.5	3.12 i	35.86 gh	87.73 fg	242.40 f	367.10 g
0	2.0	2.64 l	27.23 k	72.33 jk	220.60 j	351.40 k
1.25	0	1.66 n	21.12 l	67.28 l	213.50 k	335.20 m
1.25	0.5	3.37 f	39.95 e	88.83 f	243.90 ef	374.30 f
1.25	1.0	3.62 d	43.43 d	94.77 de	252.50 c	380.60 e
1.25	1.5	3.71 c	46.43 c	99.41 c	259.10 b	389.90 c
1.25	2.0	3.28 g	38.16 f	86.59 g	238.60 g	367.60 g
2.5	0	1.88 m	26.28 k	71.51 k	218.00 j	341.40 l
2.5	0.5	3.64 d	45.30 c	95.57 d	251.10 c	383.40 d
2.5	1.0	3.89 b	48.74 b	101.80 b	259.90 b	393.30 b
2.5	1.5	3.98 a	51.78 a	106.50 a	272.90 a	403.60 a
2.5	2.0	3.55 e	43.46 d	93.67 de	247.60 d	375.60 f
3.75	0	1.22 o	19.16 m	63.62 m	209.10 l	326.20 n
3.75	0.5	2.88 j	36.52 g	82.52 h	237.60 g	367.30 g
3.75	1.0	3.13 i	39.93 e	88.80 f	245.8 de	375.60 f
3.75	1.5	3.12 h	42.34 d	93.43 e	253.50 c	383.20 d
3.75	2.0	2.79 k	34.61 h	80.61 i	232.90 h	362.70 h
SE value		**0.0067**	**1.1129**	**0.6386**	**1.0391**	**0.6054**
Significance level		**	**	**	**	**
CV (%)		**4.40**	**2.31**	**5.31**	**3.76**	**2.29**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

4.2.3 Absolute growth rate (AGR)

Effect of Zinc (Zn)

Analysis of variance data regarding to AGR was significantly influenced by the main effect of Zn at different DAS (Appendix X Fig. 5) which significant result was also present in Table 11. Table 11, indicated that higher AGR (2.65, 3.38, 10.40 and 8.64 g plant^{-1} day^{-1}) was recorded under the treated plant of Zn @ 2.5 kg ha^{-1} at the stage between 5–20, 20–35, 35–50 and 50–65 DAS, respectively which was statistically differed from other Zn treatments. Similarly, at these stages the lower AGR (1.67, 3.14, 9.99 and 8.29 g plant^{-1} day^{-1}, respectively) was found under the treatment of without Zn fertilizer which was statistically identical to Zn @ 3.75 kg ha^{-1} at the stage between 20–35 DAS (3.15 g plant^{-1} day^{-1}) and statistically differed at rest of the data recording stages. These results revealed that AGR data was gradually increase up to flowering stage (35–50 DAS) but it was decline at harvest stage (50–65 DAS) which might be found due to the growth of black gram was much slower in harvest stage than that of other growth stages.

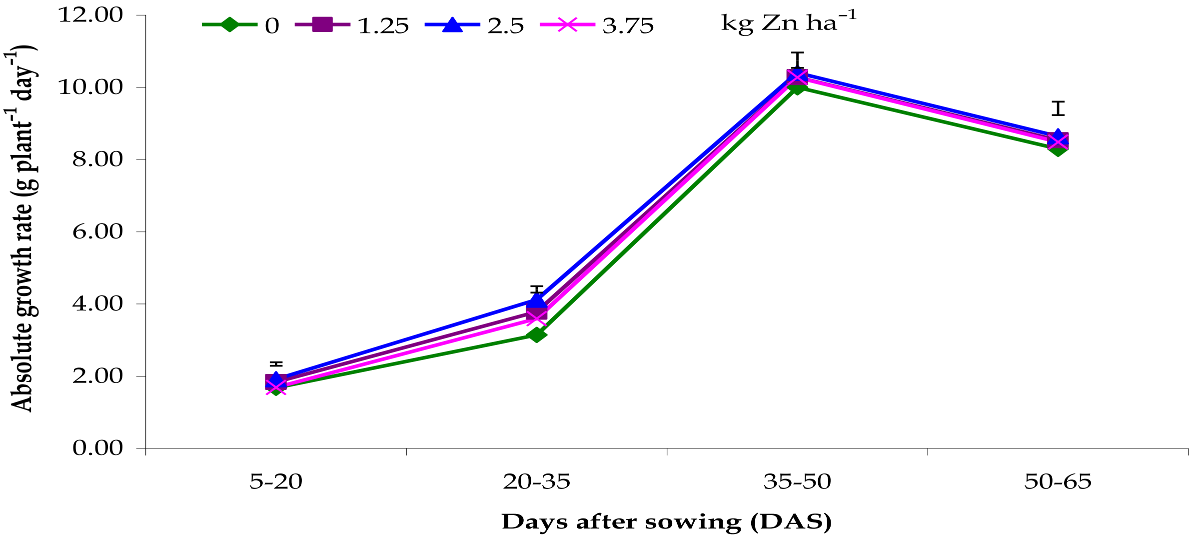

Fig. 5. Effect of Zinc (Zn) fertilizer on absolute growth rate of black gram at different days after sowing. Vertical bar represents SE value

Effect of Boron (B)

Application of B at different levels in the present study was significant on AGR during the whole data recorded period (Appendix X Fig. 6). The highest AGR (2.71, 3.51, 10.11 and 8.63 g plant^{-1} day^{-1}) was taken under the treated plant of B @ 1.5 kg ha^{-1} and the lowest AGR (1.23, 3.00, 9.69 and 7.92 g plant^{-1} day^{-1}) was recorded in without B treatment at the stages between 5–20, 20–35, 35–50 and 50–65 DAS, respectively where all the higher and lower AGR were statistically different from other treatments. However, higher AGR at the stage between 50–65 DAS (harvest stage) was statistically close to the application B @ 1.0 kg ha^{-1} (8.63 g plant^{-1} day^{-1}). These results also revealed that AGR data was gradually increase with the advancement of sowing time, however it was decline from 35–50 DAS to maturity stage (50–65 DAS) incase of the slower growth rate of black gram was found from this stages.

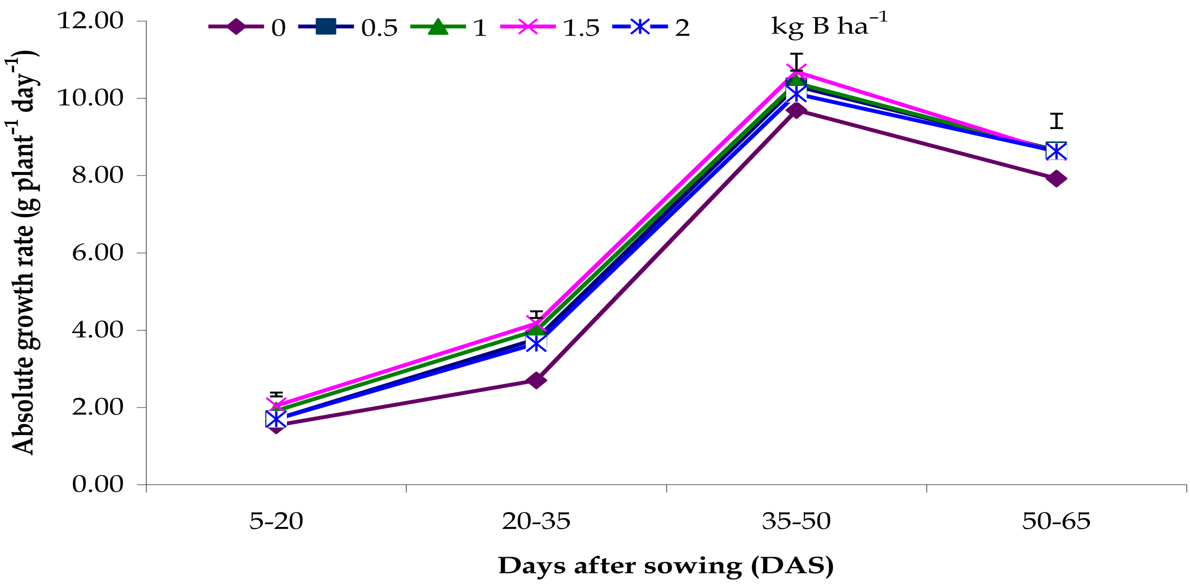

Fig. 6. Effect of Boron (B) fertilizer on absolute growth rate of black gram at different days after sowing. Vertical bar represents SE value

Interaction effect between Zn and B

Interaction effect between Zn and B showed significant variation at different DAS (Appendix X and Table 15). Among the interaction effect, the higher AGR of black gram (3.19, 3.65, 11.09, 8.72 g plant^{-1} day^{-1}) was recorded under the interaction effect of Zn @ 2.50 and B @ 1.5 kg ha^{-1} treated plant of black gram. Similarly, the lowest AGR (0.79, 2.99, 9.55 and 7.53 g plant^{-1} day^{-1}) was obtained from the interaction effect between both control of Zn and B at the stage between 5–20, 20–35, 35–50 and 50–65 DAS, respectively whereas they were statistically differed from other interactions. The result of the AGR showed that it was significantly increased with the advancement of study period. However, it was decline at harvest stage due to the lower growth of black gram were found at maturity than other stages. Besides, interaction effect between Zn @ 2.5 and B @ 1.5 were more efficient to achieve proper soil nutrient and moisture, balance pH value and higher N_2–fixation which was helpful to get higher growth of black gram as well as higher AGR.

Table 15. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on absolute growth rate (AGR) at different growth stages

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Absolute growth rate (g plant^{-1} day^{-1}) at different DAS			
		5–20	**20–35**	**35–50**	**50–65**
0	0	0.79 n	2.96 i	9.55 l	7.53 l
0	0.5	1.74 j	2.99 hi	10.20 gh	8.45 g
0	1.0	2.01 i	3.29 ef	10.04 i	8.45 g
0	1.5	2.18 gh	3.46 c	10.31 fg	8.31 h
0	2.0	1.64 k	3.01 g–i	9.89 j	8.72 c
1.25	0	1.29 l	3.08 g	9.75 k	8.12 j
1.25	0.5	2.44 e	3.24 f	10.36 ef	8.69 cd
1.25	1.0	2.65 d	3.42 cd	10.51 cd	8.54 f
1.25	1.5	2.85 c	3.53 b	10.65 bc	8.72 c
1.25	2.0	2.33 f	3.23 f	10.13 hi	8.61 e
2.5	0	1.63 k	3.02 g–i	9.77 jk	8.23 i
2.5	0.5	2.78 c	3.35 de	10.37 ef	8.83 b
2.5	1.0	2.99 b	3.54 b	10.53 cd	8.89 a
2.5	1.5	3.19 a	3.65 a	11.09 a	8.72 c
2.5	2.0	2.66 d	3.35 de	10.26 f–h	8.53 f
3.75	0	1.19 m	2.96 i	9.70 k	7.80 k
3.75	0.5	2.24 fg	3.07gh	10.34 ef	8.65 de
3.75	1.0	2.45 e	3.26 f	10.47 de	8.65 de
3.75	1.5	2.61 d	3.41 cd	10.67 b	8.65 de
3.75	2.0	2.12 h	3.07 gh	10.15 hi	8.65 de
SE value		**0.0318**	**0.0243**	**0.0448**	**0.0218**
Significance level		*	**	**	*
CV (%)		**2.40**	**4.35**	**3.76**	**5.45**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

4.2.4 Relative growth rate (RGR)

Effect of Zinc (Zn)

Main effect of Zn was significantly influenced on relative growth rate (RGR) at different growth stages (Appendix XI Fig. 7). Significant variation data was also present in Table 13, where it was found that the application of Zn @ 2.50 kg ha^{-1} was more significant to produce higher RGR during the growth period. As a result, the higher RGR (1.15, 1.47, 4.54 and 3.77 g g^{-1} day^{-1}) was recorded under the treated plant of Zn @ 2.5 kg ha^{-1} which was statistically different from other Zn treatments at the growth stages between 5–20, 20–35, 35–50 and 50–65 DAS, respectively. Similarly, at these stage, the lowest RGR

(0.73, 1.37, 4.36 and 3.62 g g^{-1} day^{-1}) was found under without Zn fertilizer treatment which statistically differed from other treatments at 5–20, 35–50 and 50–65 DAS but it was statistically identical to Zn @ 3.75 kg ha^{-1} at the stage between 20–35 DAS (1.37 g g^{-1} day^{-1}). From the above results investigation of RGR, it was found that it was significantly increase at 35–50 DAS but it was decrease at 50–65 DAS which might be found due to the lower morphological growth of black gram was much slower at maturity than other growth stages.

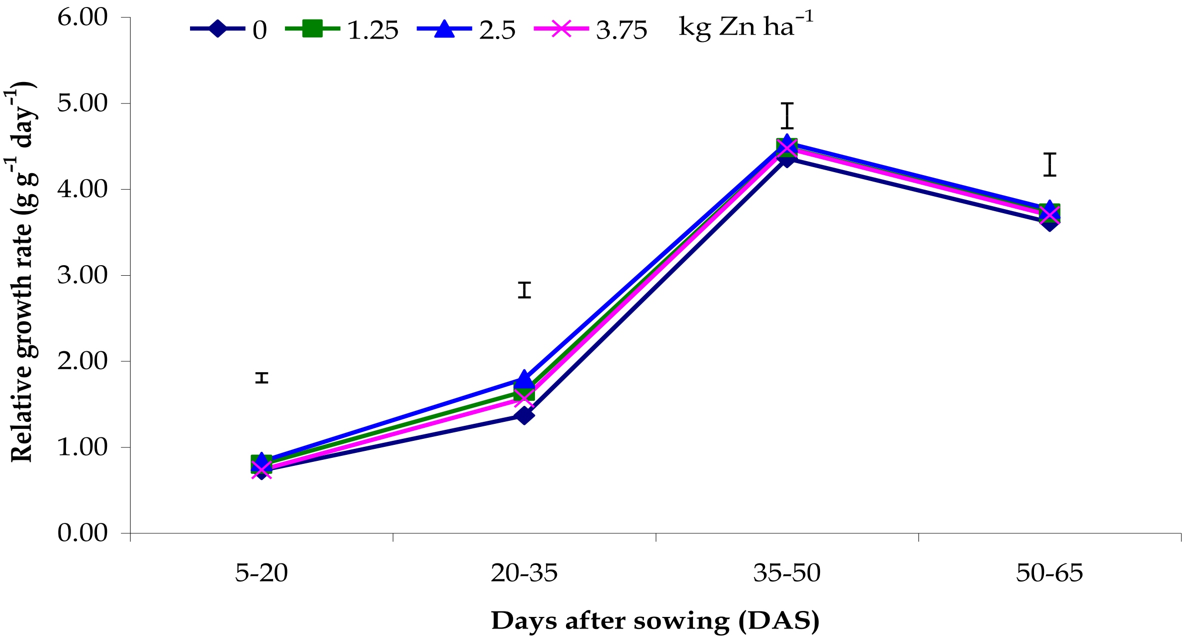

Fig. 7. Effect of Zinc (Zn) fertilizer on relative growth rate of black gram at different days after sowing. Vertical bar represents SE value

Effect of Boron (B)

Main effect of B was significantly influenced on RGR at different growth stages (Appendix XI Fig. 8). Among the B levels, B @ 1.5 kg ha^{-1} had more efficient to produced higher RGR (1.18, 1.53, 4.66 and 3.75 g g^{-1} day^{-1}) than other B levels at 5–20, 20–35, 35–50 and 50–65 DAS, respectively which was statistically identical with the B application @ both 1.0 and 2.0 kg ha^{-1} (3.77 and 3.76 g g^{-1} day^{-1}, respectively) at 50–65 DAS. On the other hand, the lowest RGR (0.54, 1.31, 4.23 and 3.45 g g^{-1} day^{-1}) was recorded in without B treatment at 5–20, 20–35, 35–50 and 50–65 DAS, respectively while it was statistically differed from other treatments.

These results revealed that, the RGR was significantly increase from 5–20 DAS to 35–50 DAS and significantly decreased from 35–50 DAS to 50–65 DAS in case of the slower growth rate of black gram was attained at this stage.

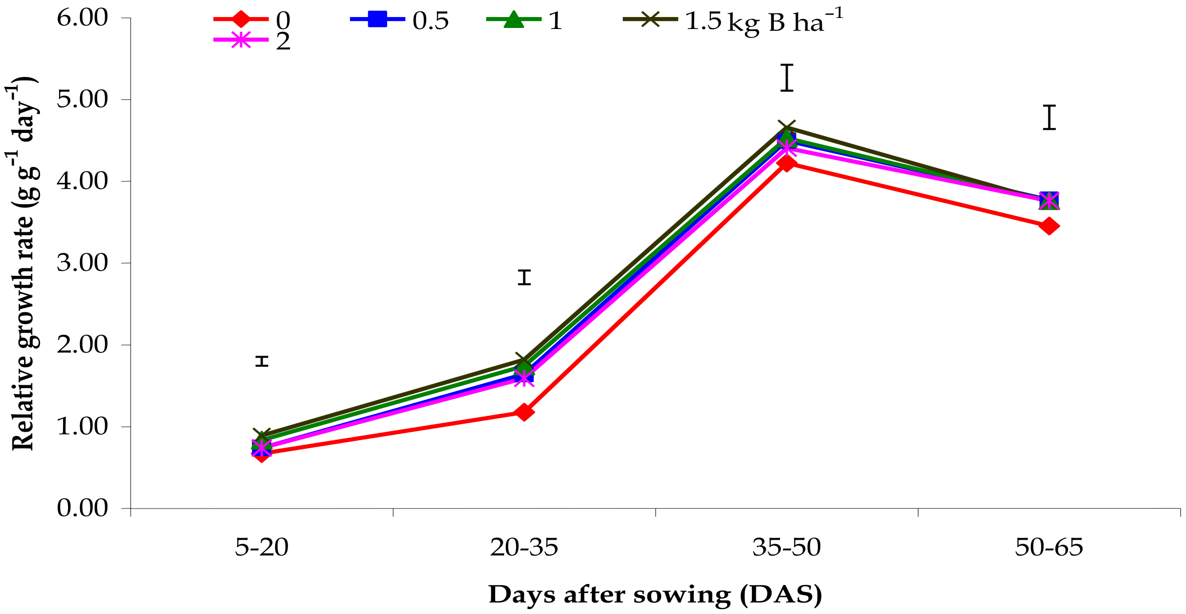

Fig. 8. Effect of Boron (B) fertilizer on relative growth rate of black gram at different days after sowing. Vertical bar represents SE value

Interaction effect between Zn and B

A significant variation was also found due to the interaction effect between Zn and B on RGR at different growth stages (Appendix XI and Table 16). The higher RGR of black gram (1.39, 1.59, 4.84 and 3.88 g g^{-1} day^{-1}) was taken from the interaction effect of Zn @ 2.50 and B @ 1.5 kg ha^{-1} at 5–20, 20–35, 35–50 and 50–65 DAS, respectively which was statistically differed from other interaction. However, it was statistically close with the interaction effect of Zn @ 2.5 kg ha^{-1} and B @ 1.0 kg ha^{-1} at 50–65 DAS (3.85 g g^{-1} day^{-1}). Similarly, the lowest RGR (0.35, 1.29, 4.16 and 3.28 g g^{-1} day–^{1}) was recorded in interaction of both control at 5–20, 20–35, 35–50 and 50–65 DAS, respectively which was statistically identical with the interaction treatments of $Zn_0 \times B_{0.5}$, $Zn_0 \times B_{2.0}$, $Zn_{1.25} \times B_0$, $Zn_{2.5} \times B_0$, $Zn_{3.75} \times B_0$ and $Zn_{3.75} \times B_{0.5}$ (1.30, 1.31, 1.34, 1.31, 1.29 and 1.34 g g^{-1} day^{-1}, respectively) at 20–35 DAS. These results indicated that the RGR was significantly increased up to 35–50 DAS and decreased at 50–65 DAS which might be due to the lower growth of black gram were found at this stage.

Besides, interaction effect between Zn @ 2.5 and B @ 1.5 were more efficient to achieve proper soil nutrient and moisture, balance pH value and higher N_2–fixation which was helpful to get higher growth of black gram as well as higher RGR.

Table 16. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on relative growth rate (RGR) at different growth stages

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Relative growth rate (g g^{-1} day^{-1}) at different DAS			
		5–20	20–35	35–50	50–65
0	0	0.35 m	1.29 g	4.16 m	3.28 i
0	0.5	0.76 k	1.30 g	4.44 g–i	3.68 e
0	1.0	0.88 j	1.44 ef	4.38 j	3.69 e
0	1.5	0.95 i	1.51 b–d	4.49 fg	3.63 f
0	2.0	0.72 k	1.31 g	4.31 k	3.80 bc
1.25	0	0.57 l	1.34 g	4.25 l	3.54 g
1.25	0.5	1.06 fg	1.41 f	4.52 ef	3.79 c
1.25	1.0	1.16 de	1.49 b–e	4.58 d	3.72 de
1.25	1.5	1.24 c	1.54 a–c	4.64 bc	3.80 bc
1.25	2.0	1.01 gh	1.41 f	4.42 ij	3.75 cd
2.5	0	0.71 k	1.31 g	4.26 l	3.59 fg
2.5	0.5	1.21 cd	1.46 d–f	4.52 ef	3.85 ab
2.5	1.0	1.30 b	1.54 ab	4.59 cd	3.88 a
2.5	1.5	1.39 a	1.59 a	4.84 a	3.80 bc
2.5	2.0	1.16de	1.46d–f	4.47 f–h	3.72 de
3.75	0	0.52 l	1.29 g	4.23 l	3.40 h
3.75	0.5	0.98 hi	1.34 g	4.51 f	3.77 cd
3.75	1.0	1.07 f	1.42 f	4.57 de	3.77 cd
3.75	1.5	1.14 e	1.49 c–e	4.65 b	3.77 cd
3.75	2.0	0.93 ij	1.34 g	4.43 h–j	3.77 cd
SE value		**0.0139**	**0.0106**	**0.0195**	**0.0095**
Significance level		*	**	**	**
CV (%)		**2.63**	**4.40**	**4.76**	**3.45**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

4.2.5 Crop growth rate (CGR)

Effect of Zinc (Zn)

The data on CGR of black gram was significantly influenced due to the main effect of Zn at different growth stages (Appendix XII Fig. 9). From the Fig. 9, it was appeared that the higher CGR (0.08, 0.10, 0.31 and 0.26 g m^{-2} day^{-1}) was found in 2.50 kg ha^{-1} Zn at the growth stage between 5–20, 20–35, 35–50 and 50–65 DAS, respectively while Zn @ 1.25 kg ha^{-1} were statistically identical at the stage between 20–35 DAS (0.09 g m^{-2} day^{-1}) and 35–50 DAS (0.31 g m^{-2} day^{-1}) and statistically close at the stage between 5–20 DAS (0.07 g m^{-2} day^{-1}) and 50–65 DAS (0.26 g m^{-2} day^{-1}). Application of Zn @ 3.75 was also statistically at 35–50 DAS (0.31 g m^{-2} day^{-1}) and statistically closes at 5–20 DAS (0.06 g m^{-2} day^{-1}) and 50–65 DAS (0.25 g m^{-2} day^{-1}). In another observation, without Zn treated plant recorded the lowest CGR (0.05, 0.09, 0.29 and 0.25 g m^{-2} day^{-1}) at 5–20, 20–35, 35–50 and 50–65 DAS, respectively which was statistically close with Zn @ 1.25 kg ha^{-1} at 5–20 DAS and 50–65 DAS, and Z @ 3.75 kg ha^{-1} at 5–20 DAS, and 50–65 DAS.

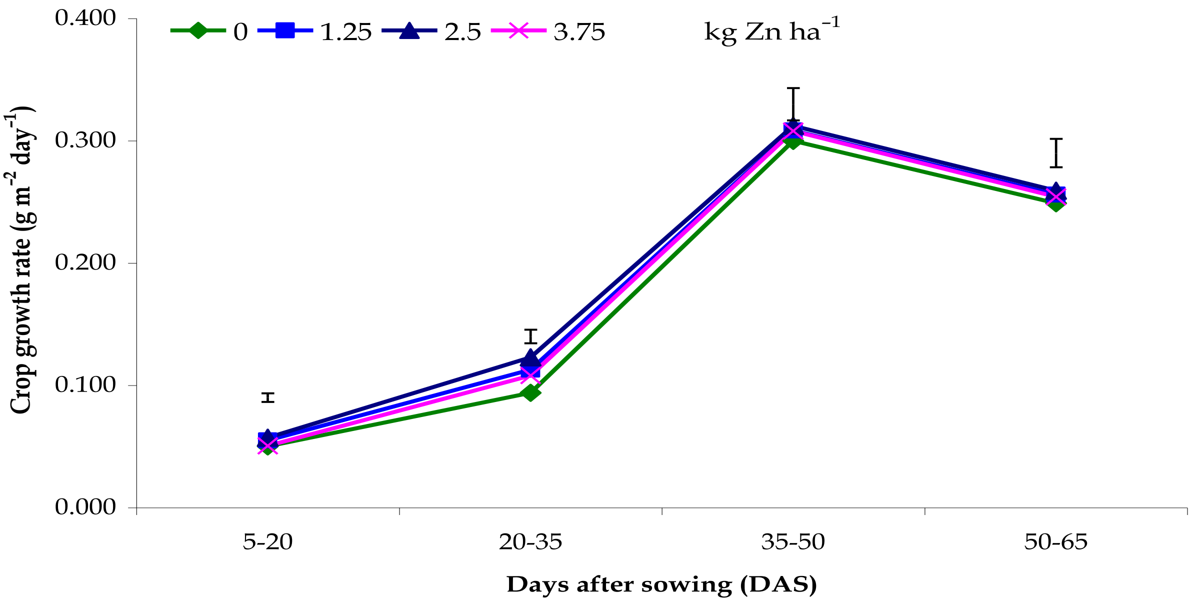

Fig. 9. Effect of Zinc (Zn) fertilizer on crop growth rate of black gram at different days after sowing. Vertical bar represents SE value

Effect of Boron (B)

Boron application was also showed significant difference on CGR at different growth stages (Appendix XII and Fig. 10). The higher CGR at the stage between 5–20, 2–35 and 35–50 DAS (0.08, 0.11 and 0.32 g m^{-2} day^{-1}) were recorded in B @ 1.50 kg ha^{-1} which was statistically identical with B @ 0.5, 1.0 and 2.0 kg ha^{-1} (0.07, 0.08 and 0.07 g m^{-2} day^{-1}, respectively) at 5–20 DAS and statistically close to B @ 1.0 kg ha^{-1} (0.10 g m^{-2} day^{-1}) at 20–35 DAS. AT the stage between 50–65 DAS, the higher CGR (0.2590 g m^{-2} day^{-1}) was found in B @ 0.5 kg ha^{-1} which was also statistically identical with B @ 1.0, 1.5 and 2.0 kg ha^{-1} (0.26, 0.26 and 0.26 g m^{-2} day^{-1}). Among the studied growth stages, the lowest CGR (0.04, 0.09, 0.29 and 0.23 g m^{-2} day^{-1}) was recorded in the treatment of without B which was statistically close to B @ 2.0 kg ha^{-1} at 20–35 DAS (0.09 g m^{-2} day^{-1}).

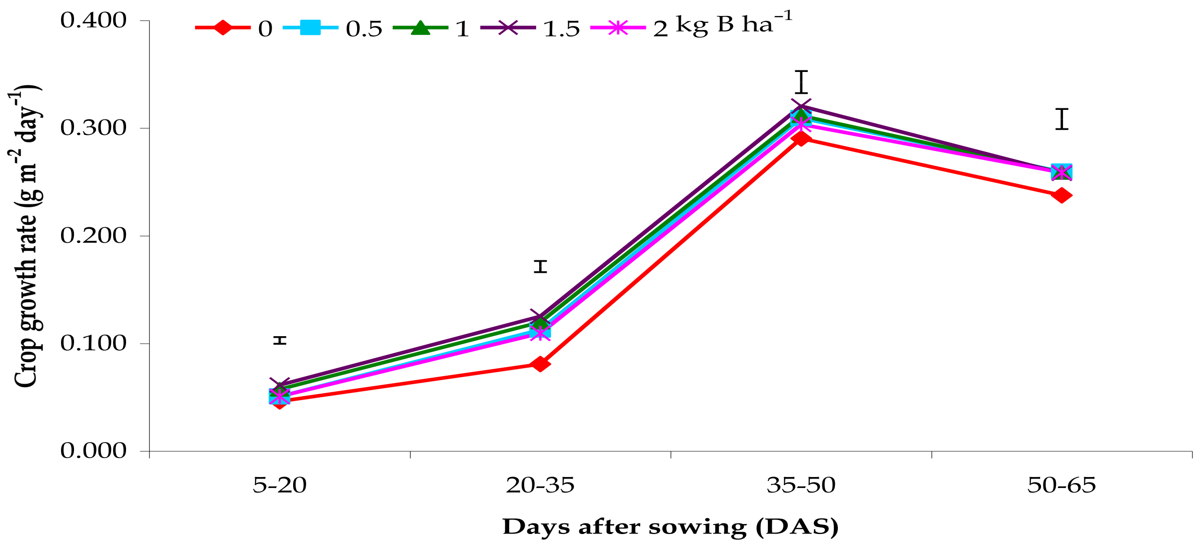

Fig. 10. Effect of Boron (B) fertilizer on crop growth rate of black gram at different days after sowing. Vertical bar represents SE value

Interaction effect between Zn and B

Interaction effect of different levels of Zn and B fertilizer was significantly influenced on CGR at different growth stages (Appendix XII and Table 17). Among the interaction effect, Zn @ 2.5 × B @ 1.5 kg ha^{-1} recorded the higher CGR (0.09, 0.11 and 0.33 g m^{-2} day^{-1}) at 5–20, 20–35 and 35–50 DAS, respectively while it was statistically close with the all interaction except $Zn_0 \times B_0$ at 5–20 DAS, $Zn_0 \times B_0$ and $Zn_{3.75} \times B_0$ at 20–35 DAS, and $Zn_{1.25} \times B_{1.5}$, $Zn_{3.75} \times B_{1.5}$, $Zn_{1.25} \times B_{1.0}$, $Zn_{2.5} \times B_{1.0}$ at 35–50 DAS whereas $Zn_{1.25} \times B_{1.5}$, and $Zn_{3.75} \times B_{1.5}$, and $Zn_{1.25} \times B_{1.0}$ and $Zn_{2.5} \times B_{1.0}$ were statistically identical. On the other hand, the lowest CGR (0.02, 0.09, 0.29 and 0.23 g m^{-2} day^{-1}) was recorded in interaction of both controls at 5–20, 20–35, 35–50 and 50–65 DAS, respectively.

Table 17. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on crop growth rate (CGR) at different growth stages

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Crop growth rate (g m^{-2} day^{-1}) at different DAS			
		5–20	**20–35**	**35–50**	**50–65**
0	0	0.02 b	0.09 b	0.29 f	0.23e
0	0.5	0.05 ab	0.09 ab	0.31 b–e	0.253 a–c
0	1.0	0.06 ab	0.09 ab	0.30 b–f	0.253 a–c
0	1.5	0.07 ab	0.10 ab	0.31 b–e	0.25 a–d
0	2.0	0.05 ab	0.09 ab	0.29 c–f	0.26 a–c
1.25	0	0.04 ab	0.09 ab	0.29 d–f	0.24 cd
1.25	0.5	0.07 ab	0.09 ab	0.31 b–d	0.26 a–c
1.25	1.0	0.08 ab	0.10 ab	0.32 a–c	0.26 a–c
1.25	1.5	0.09 ab	0.11 ab	0.32 ab	0.26 a–c
1.25	2.0	0.07 ab	0.09 ab	0.30 b–f	0.26 a–c
2.5	0	0.05 ab	0.09 ab	0.29 d–f	0.25 b–d
2.5	0.5	0.08 ab	0.10 ab	0.31 b–d	0.27 ab
2.5	1.0	0.09 a	0.11 ab	0.32 a–c	0.27 a
2.5	1.5	0.09 a	0.11 a	0.33 a	0.27 a–c
2.5	2.0	0.08 ab	0.10 ab	0.31 b–e	0.26 a–c
3.75	0	0.04 ab	0.09 b	0.29 ef	0.23 de
3.75	0.5	0.07 ab	0.09 ab	0.31 b–e	0.26 a–c
3.75	1.0	0.07 ab	0.09 ab	0.31 bc	0.26 a–c
3.75	1.5	0.08 ab	0.10 ab	0.32 ab	0.26 a–c
3.75	2.0	0.06 ab	0.09 ab	0.31 b–f	0.26 a–c
SE value		**0.0010**	**0.0007**	**0.0013**	**0.0007**
Significance level		**	**	**	**
CV (%)		**3.66**	**2.38**	**3.73**	**4.46**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

4.3 Effect of Zn and/or B on yield and yield contributing characters

4.3.1 Number of pods plant^{-1}

Effect of Zinc (Zn)

A highly significant variation was found due to the effect of Zn on number of pods plant^{-1} at harvest (Appendix XIII and Fig. 11). Among the Zn levels, Zn @ 2.5 kg ha^{-1} recorded the maximum number of pods plant^{-1} (48.99) whereas it was statistically differed from other Zn levels. In contrast, the minimum number of pods plant^{-1} (42.49) was obtained in without Zn fertilizer which was also statistically differed from other B levels at 5% level of probability. Similar experiment was also conducted by Dashadi *et al*. (2013) who reported that the Zn applied to the soil, had a significant effect on number of pods plant^{-1}. Salehin and Rahman (2012) also found that Zn spray (0 and 1 g L^{-1}) was significant at 1% probability on yield and yield components of *Phaseolus vulgaris*. In maturity time, seed yield, 100-seed weight, number of pods plant^{-1} and number of seeds pod^{-1} had higher in Zn application. Quddus *et al*. (2012); Khorgamy and Farnia (2009) Valenciano *et al*. (2007) and many other scientists were found significant variation in pod production by the Zn application.

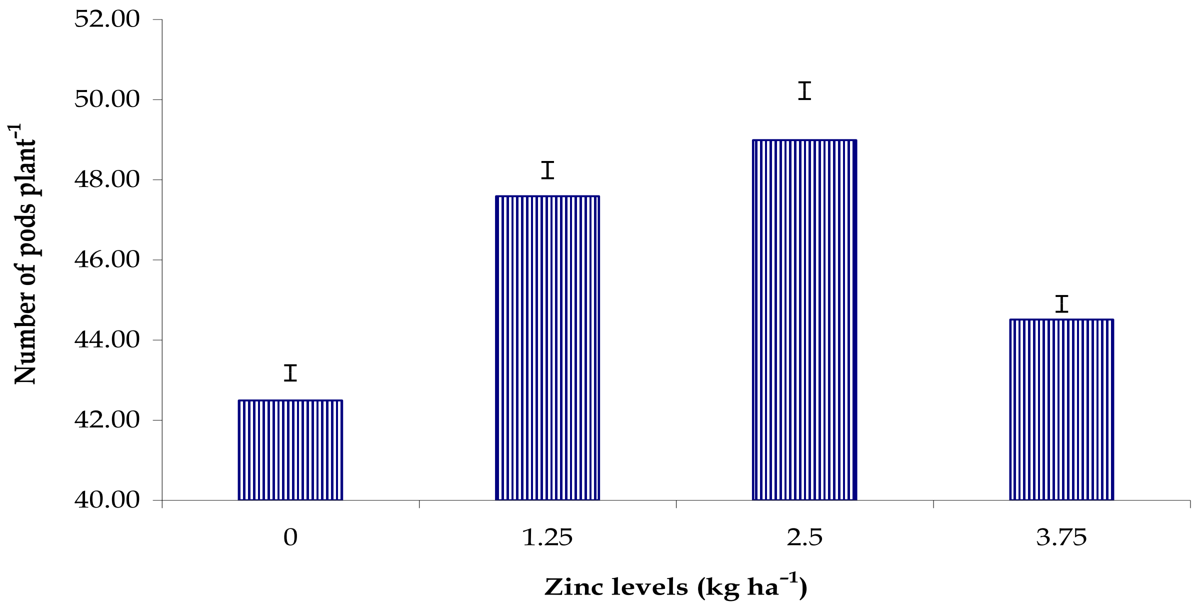

Fig. 11. Effect of Zinc (Zn) fertilizer on number of pods plant^{-1} at harvest. Vertical bar represents SE value

Effect of Boron (B)

Analysis of variance data regarding to production of pods plant^{-1} was significantly influenced by the effect of different level of B fertilizer (Appendix XIII and Fig.12). Fig. 6, indicated significant difference whereas the B @ 1.5 kg ha^{-1} produces the maximum number of pods plant^{-1} (51.62) which was significantly differed from other treatments. On the other hand, without B recorded the significantly minimum number of pods plant^{-1} (37.50) which was also statistically differed from other B levels. This result indicated that B at 1.5 kg ha^{-1} had highly significant and more efficient to produce more pods. Pandey and Gupta (2013) conducted a field experiment to study the effect of foliar application B on reproductive biology and seed quality of black gram (*Vigna mungo*). They reported that at all the three concentrations of B at all stages increased the yield parameters like number of pods while B application also improved the seed yield of black gram. Valenciano *et al*. (2011) also reported that B @ 241.00 g ha^{-1} produces the higher results regarding to pods plant^{-1}. Similarly, Kaisher *et al*. (2010); Dixit and Elamathi (2007) also found similar results on pods production plant^{-1} where application of B were significant in pods production plant^{-1}.

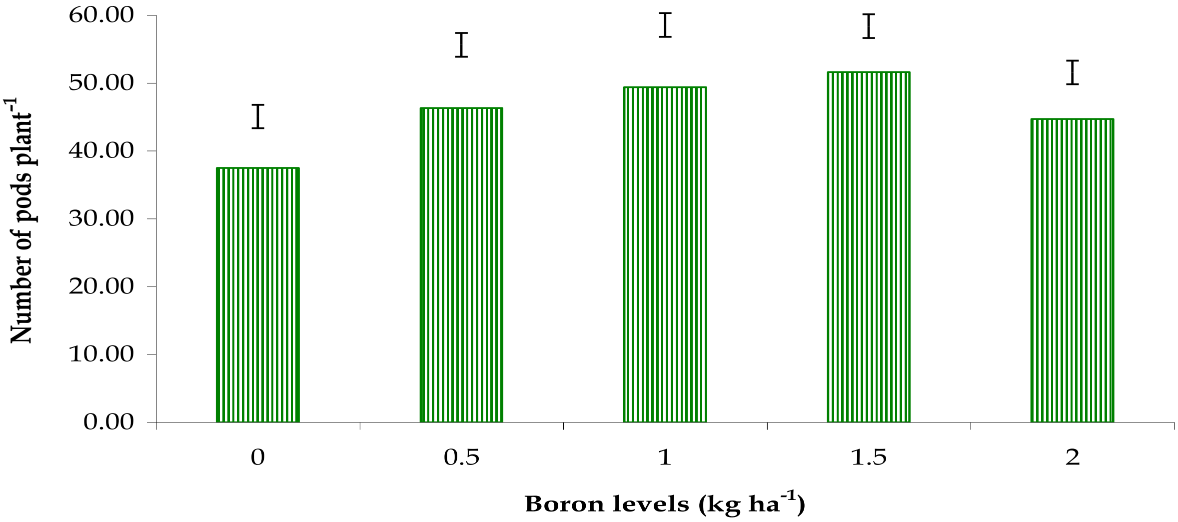

Fig. 12. Main effect of Boron (B) fertilizer on number of pods plant^{-1} at harvest. Vertical bar represent SE value

Interaction effect between Zn and B

Interaction effect between Zn and B was significantly influenced on the production of pods plant^{-1} (Appendix XIII and Table 18). The maximum number of pods plant^{-1} (55.20) was found from the interaction effect of Zn @ 2.5 kg ha^{-1} and B @ 1.5 kg ha^{-1} which was statistically different from other combinations. Similarly, the minimum number of pods plant^{-1} (34.93) was recorded from the interaction of both controls which was also statistically different from other interaction treatments. Similarly, Valenciano *et al*. (2010) also found significant variation in pod production with the interaction effect of Zn, B and Mo applications and they found that their interaction improved the number of pods plant^{-1}.

4.3.2 Pod length

Effect of Zinc (Zn)

The analysis of variance data regarding to pod length was significant due to the interaction effect of Zn and B at harvest (Appendix XIII and Fig. 13) where Zn @ 2.5 and B @ 1.5 kg ha^{-1} showed the better results than other treatment combinations. As a result, interaction effect of Zn @ 2.5 and B @ 1.5 kg ha^{-1} showed the longest pod (5.06 cm) which was followed by Zn @ 1.25 kg ha^{-1} (4.80 cm) but they were not statistically identical. In contract, the shortest pod (4.70 cm) was taken from the untreated or control or without Zn levels which was statistically identical (4.75) with higher doses of Zn (3.75 kg ha^{-1}).

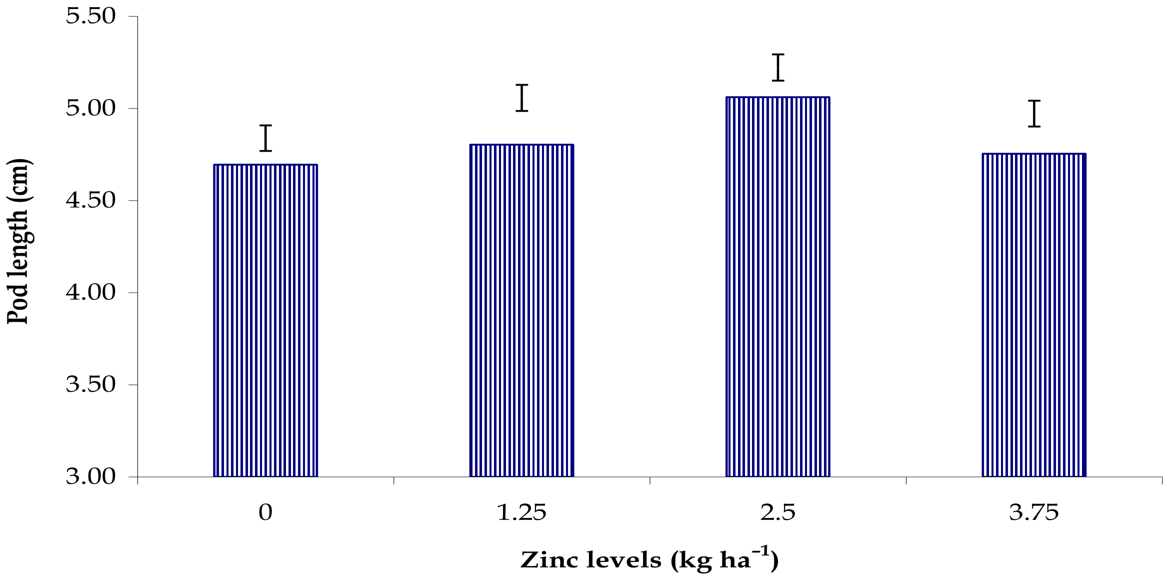

Fig. 13. Effect of Zinc (Zn) fertilizer on length of pod at harvest. Vertical bar represents SE value

Effect of Boron (B)

Pod length data was also showed significant variation due to the effect of B in this study (Appendix XIII and Fig. 14). Among the various levels of B @ 1.5 kg ha^{-1} produced significantly the longest pod (4.99 cm) which was statistically identical with other doses of B *viz.*, B @ 1.0 kg ha^{-1} (4.93 cm) and B @ 2.0 kg ha^{-1} (4.94 cm). As a result, control treatment obtained the shortest pod (4.52 cm) which was statistically differed from other B levels.

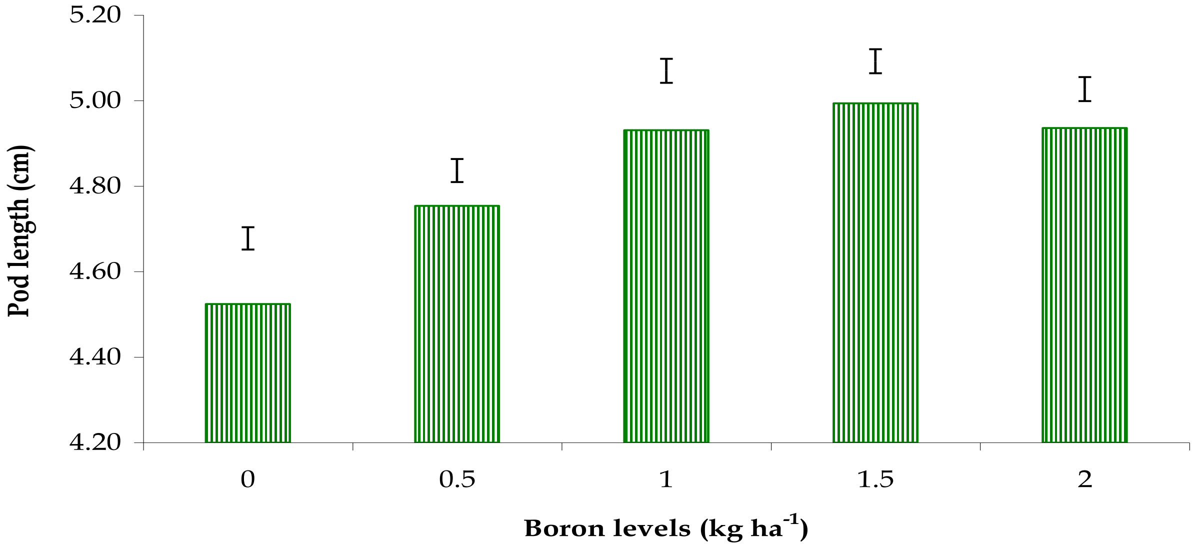

Fig. 14. Effect of Boron (B) fertilizer on length of pod at harvest. Vertical bar represents SE value

Interaction effect between Zn and B

A highly significant variation ($P \leq 0.01$) was found due to the interaction effect of Zn and B on pod length at harvest (Appendix XIII and Table 18). Among the interaction treatments, interaction effect between Zn @ 2.50 and B @ 2.0 kg ha^{-1} showed the longest pod (5.73 cm) which was significantly close (5.13 cm) to the interaction effect between Zn @ 2.5 and B @ 1.5 and significantly differed from other all interactions. Among other interactions, control treatment of both fertilizers recorded the shortest pod (4.47 cm) which was statistically identical among other all treatments at 5% level (Table 18).

4.3.3 Number of seeds pod^{-1}

Effect of Zinc (Zn)

Analysis of variance data showed significant variation found due to the effect of Zn regarding to seeds plant^{-1} at harvest (Appendix XIII and Fig. 15). The maximum number of seeds plant^{-1} (6.98) was recorded in Zn @ 2.50 kg ha^{-1} and the minimum number of seeds plant^{-1} (6.78) was recorded in control treatment. Salehin and Rahman (2012) also found that Zn spray (0 and 1 g L^{-1}) was significant at 1% probability on yield and yield components of *Phaseolus vulgaris*. In maturity time, number of seeds pod^{-1} had higher in Zn application. Quddus *et al*. (2012) also found that the maximum and minimum number of seeds pod^{-1} was recorded in the treatment T_2= $N_{21}P_{23}K_{30}S_{18}Zn_2B_{1.5}$. Similarly, Khorgamy and Farnia (2009) found that Zn had significant effects on number of seeds pod^{-1}.

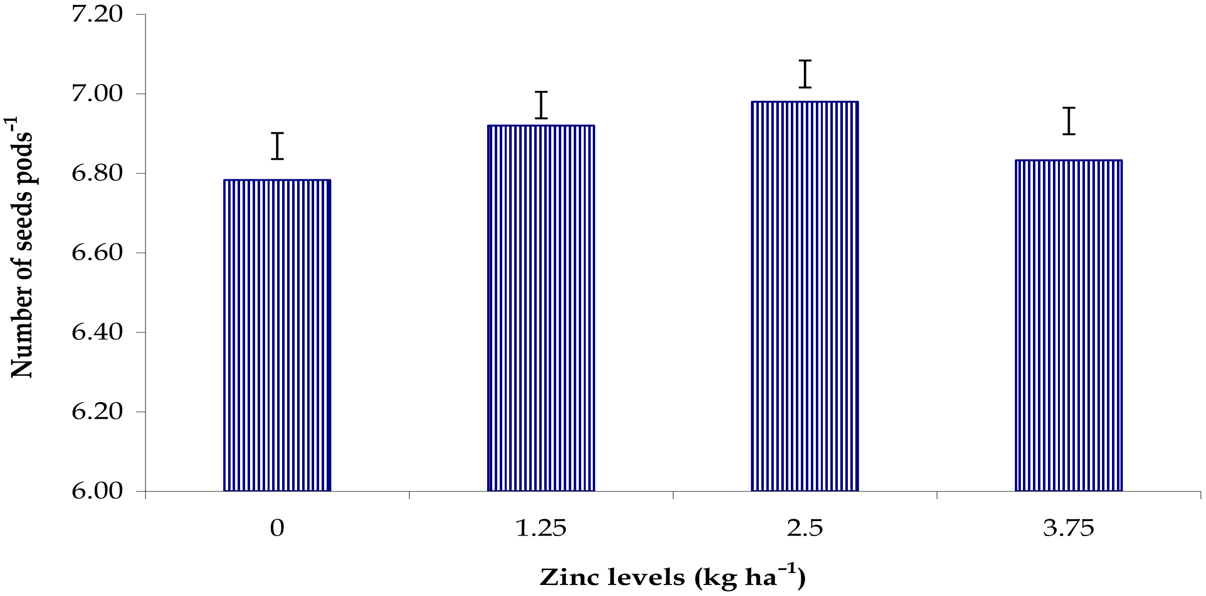

Fig. 15. Effect of Zinc (Zn) fertilizer on number of seeds pod^{-1} of black gram at different days after sowing. Vertical bar represents SE value

Effect of Boron (B)

A significant variation was also found due to the effect of B fertilizer on seeds plant^{-1} at harvest (Appendix XIII and Fig. 16). Among the B levels, B @ 1.5 kg ha^{-1} produced significantly the maximum seeds plant^{-1} (7.11) while control treatment obtained the minimum number of seeds plant^{-1} (6.65) whereas all the B level were statistically differed with each other at 5% level. This result indicated that B @1.5 kg ha^{-1} had highly effective to produce more seeds in case of the treatment was more efficient to get proper soil nutrient and moisture content. The result of the present study was agreed by Pandey and Gupta (2013) who found that the application of B had significant effect on seeds production pod^{-1}. They found that after 32 days of sowing B application significantly increased the number of seeds formed plant^{-1} of blackgram (*Vigna mungo*). Valenciano *et al*. (2011) also found that B_1 (241.00 g ha^{-1}) produced maximum seeds pod^{-1} in chickpea and Kaisher *et al*. (2010) found that B at 5 kg ha^{-1} significantly increased number of seeds pod^{-1} than that of other B levels.

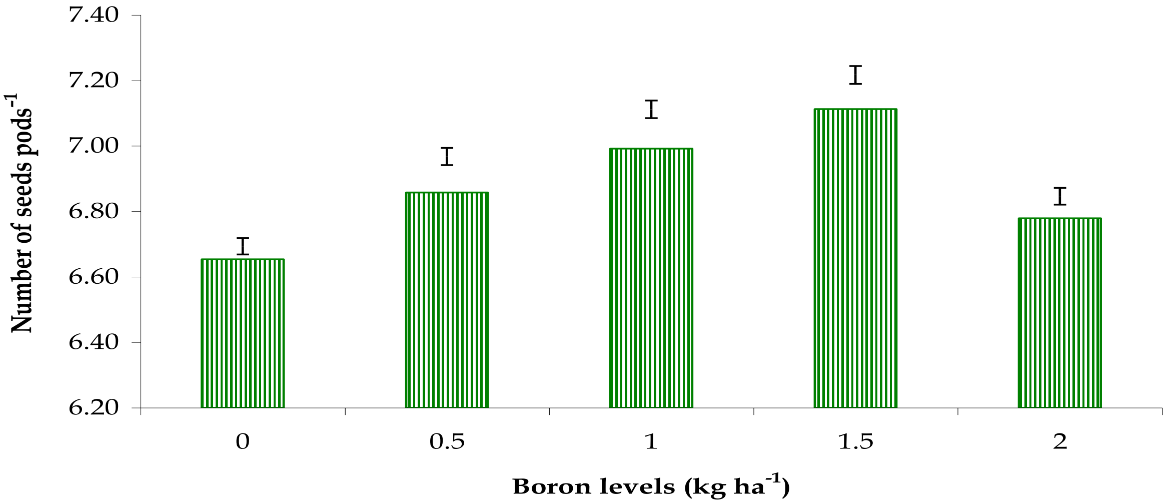

Fig. 16. Effect of Boron (B) fertilizer on number of seeds pod^{-1} at harvest. Vertical bar represents SE value

Interaction effect between Zn and B

A significant variation was also found by the interaction effect between Zn and B on seed production plant^{-1} at harvest (Appendix XIII and Table 17). Among the interaction treatments, the maximum number of seeds plant^{-1} (7.27) was found from the interaction effect between Zn @ 2.5 kg ha^{-1} and B @ 1.5 kg ha^{-1} and it was statistically different from other treatment combinations. Similarly, the minimum number of seeds plant^{-1} (6.60) was recorded from control. while similar results were also obtained by the interaction effect between higher doses of Zn (3.75 kg ha^{-1}) and without B.

4.3.4 Thousand seed weight

Effect of Zinc (Zn)

Thousand seeds weight showed significant variation due to the effect of Zn fertilizer (Appendix XIII and Fig. 17). Application of Zn @ 2.5 kg ha^{-1} recorded the higher weight of 1000–seed of black gram (41.60 g) which was statistically close (41.46 g) by the application of Zn @ 1.5 kg ha^{-1} and statistically differed from other Zn levels. Similarly, control treatment recorded the lowest weight of 1000–seed (40.54 g) which was statistically differed from other treatments. This result indicated that the Zn application @ 2.5 kg ha^{-1} were more efficient in soil which supplying the more nutrients in plants and helped to generate the larger seeds than untreated and other treated plants as well as higher 1000–seed weight were achieved. Similar experiment was also conducted by Dashadi *et al*. (2013) who reported that the Zn applied to the soil had a significant effect on hundred seed weight. Salehin and Rahman (2012) also found that zinc spray (0 and 1 g L^{-1}) was significant at 1% probability on 100–seed weight of *Phaseolus vulgaris*. In maturity 100 seed weight had higher in Zn application. Similarly, Quddus *et al*. (2011) also found that the treatment T_2= $N_{21}P_{23}K_{30}S_{18}Zn_2B_{1.5}$ recorded the average highest 100–seed weight (11.88 g).

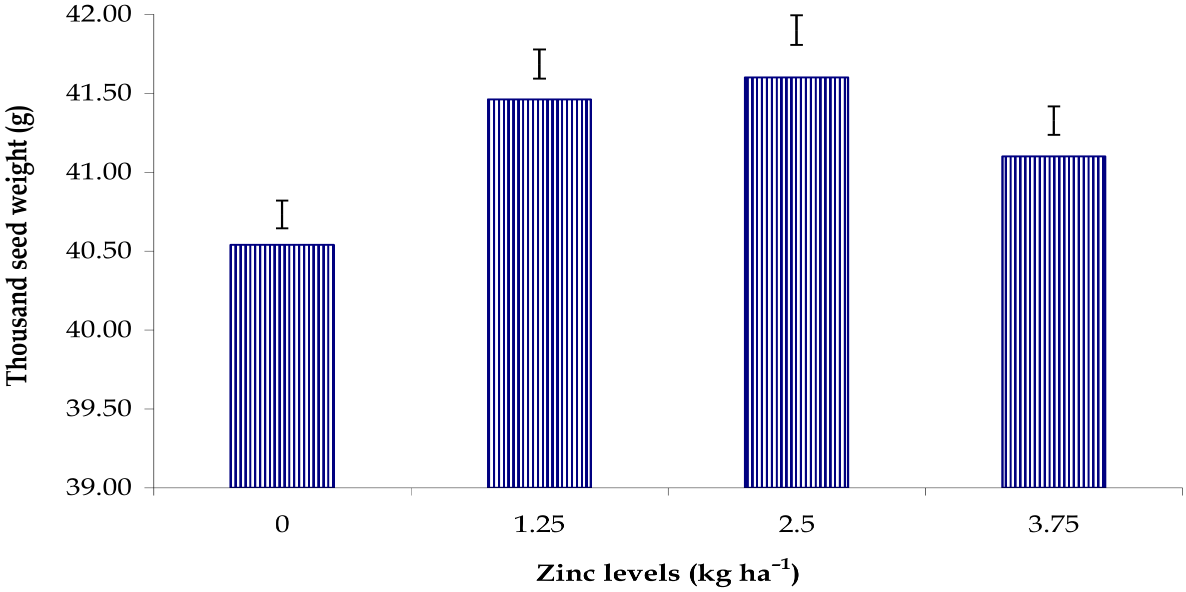

Fig. 17. Effect of Zinc (Zn) fertilizer on thousand seed weight at harvest. Vertical bar represents SE value

Effect of Boron (B)

Analysis of variance data on 1000–seed weight was also significantly influenced by the effect of B fertilizer (Appendix XIII and Fig. 18). Significant variation data on 1000–seed had higher (41.75 g) in B @ 1.5 kg ha^{-1} and it was statistically identical with the B application @ 1.0 kg ha^{-1} (41.57 g) and statistically close (41.37 g) to the B application @ 0.5 kg ha^{-1}. Rest of the B levels, the lowest weight of 1000–seed (40.19 g) in control treatment and it was statistically differed among all other treatments. In order to investigate the effect of different levels of Mo, B and Zn levels on grain yield and some physiological characteristics of chickpea was carried out by Valenciano *et al*. (2011) who reported that B_1 (241.0 g ha^{-1}) produces the higher results regarding to 1000–seed weight (294.77 g plant^{-1}, respectively) and yield (6.30 g plant^{-1}). Kaisher *et al*. (2010) and Dixit and Elamathi (2007) found that the B at 5 kg ha^{-1} and B (0.2%), respectively significantly increased 1000–seed weight.

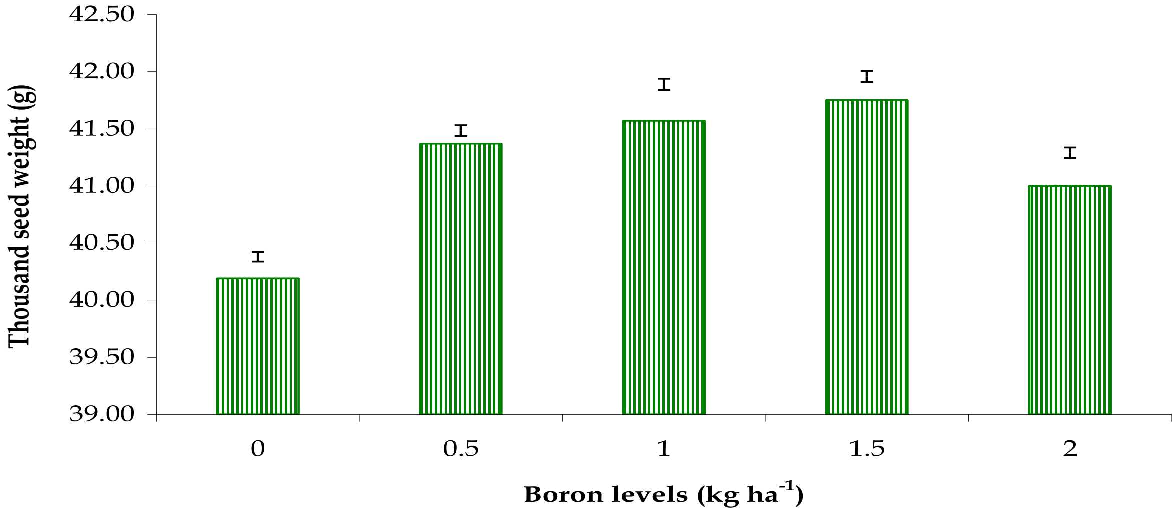

Fig. 18. Effect of Boron (B) fertilizer on thousand seed weight at harvest. Vertical bar represents SE value

Interaction effect between Zn and B

Weight of 1000–seed was significantly influenced by the interaction effect of Zn and B fertilizer (Appendix XIII and Table 18). The highest weight of 1000–seeds (42.03 g) was recorded by the interaction effect between Zn @ 2.50 and B @ 1.5 kg ha^{-1} which was statistically identical with the interaction effect of 1.5 kg ha^{-1} of both Zn and B fertilizer (41.98 g) and statistically close with the most interaction treatments. On the other hand, the lowest weight of 1000–seed (39.67 g) was recorded from the treatment combination of $Zn_0 \times B_0$ (without Zn and B) which was also statistically differed from other treatments. It was probably due to the fact that the Zn fertilizer @ 2.50 kg ha^{-1} along with B @ 1.5 kg ha^{-1} were more efficient than other interactions for supplied sufficient plant nutrients in soil which ultimately gave the heaviest seed of black gram.

Table 18. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on different yield contributing characters of black gram at harvest

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Number of pods plant^{-1}	Length of pod (cm)	Number of seeds pod^{-1}	Thousand seed weight (g)
0	0	34.93 r	4.47 b	6.60 j	39.67 i
0	0.5	43.13 m	4.68 b	6.78 gh	40.81 d–h
0	1.0	45.00 k	4.82 b	6.83 e–g	40.98 b–g
0	1.5	47.20 i	4.88 b	6.97 d	41.21 a–f
0	2.0	42.20 n	4.63 b	6.73 hi	40.05 hi
1.25	0	38.93 p	4.53 b	6.70 i	40.38 f–i
1.25	0.5	48.13 g	4.78 b	6.88 e	41.77 a–c
1.25	1.0	52.00 d	4.96 b	7.07 c	41.78 a–c
1.25	1.5	54.00 b	5.02 b	7.17 b	41.98 a
1.25	2.0	44.87 k	4.72 b	6.78 gh	41.39 a–e
2.5	0	39.33 o	4.58 b	6.72 i	40.55 e–i
2.5	0.5	49.07 f	4.82 b	6.95 d	41.82 a–c
2.5	1.0	53.73 c	5.03 b	7.10 c	41.92 ab
2.5	1.5	55.20 a	5.13 ab	7.27 a	42.03 a
2.5	2.0	47.60 h	5.73 a	6.87 ef	41.69 a–d
3.75	0	36.80 q	4.51 b	6.60 j	40.17 g–i
3.75	0.5	44.87 k	4.73 b	6.82 fg	41.07 a–g
3.75	1.0	46.73 j	4.91 b	6.97 d	41.59 a–d
3.75	1.5	50.07 e	4.95 b	7.05 c	41.79 a–c
3.75	2.0	44.07 l	4.67 b	6.73 hi	40.89 c–h
SE value		**0.0573**	**0.2233**	**0.0136**	**0.2838**
Significance level		**	**	*	*
CV (%)		**2.22**	**8.01**	**4.34**	**5.19**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

4.3.5 Grain yield

Effect of Zinc (Zn)

A significant variation was found to be the effect of Zn fertilizer on grain yield of black gram (Appendix XIV and Table 19). Among the different levels of Zn, grain yield had higher (1.54 t ha^{-1}) in Zn @ 2.5 kg ha^{-1} which was statistically differed from other treatments. Similarly, control treatment gave the comparatively lower grain yield (1.470 t ha^{-1}) which was also statistically different from other treatments. However, Zn application @ 1.25 and 3.75 kg ha^{-1} produced statistically identical yield of black gram grain (1.51 and 1.51 t ha^{-1}, respectively). These results revealed that grain yield of black gram was more significant than control which results are agreed to the findings of Dashadi *et al*. (2013) who found that the Zn applied to the soil, had a significant effect on seed yield of black gram. Ali and Mahmoud (2013) also found that the highest values of seed weight plant^{-1} were obtained when Zn foliar application was used at rate of 500 ppm. Similarly, Quddus *et al*., (2011) also found that the treatment T_2= $N_{21}P_{23}K_{30}S_{18}Zn_2B_{1.5}$ produced significantly the highest average seed yield (1524 kg ha^{-1}) and stover yield (4049 kg ha^{-1}).

Table 19. Effect of Zinc (Zn) fertilizers on various yield characters of black gram at harvest

Different levels of Zn (kg ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
0	1.47 c	3.62 c	5.09 c	28.86 b
1.25	1.52 b	3.67 b	5.19 b	29.26 a
2.5	1.55 a	3.69 a	5.24 a	29.47 a
3.75	1.52 b	3.67 b	5.18 b	29.25 a
SE value	**0.0022**	**0.0027**	**0.0026**	**0.0910**
Significance levels	**	**	**	**
CV (%)	**3.57**	**5.29**	**4.19**	**1.21**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Effect of Boron (B)

A significant difference was found to be the effect of different doses of B fertilizer on grain yield (Appendix XIV and Table 20). Among the different doses of B, B @ 1.5 kg ha^{-1} gave the highest grain yield (1.57 t ha^{-1}) which was statistically similar by the B application @ 1.0 kg ha^{-1} (1.55 t ha^{-1}). Among other doses of B, control B treatment gave the lowest grain yield (1.41 t ha^{-1}) which was statistically differed from other doses of B. Similarly, Valenciano *et al*. (2011) also found significant variation in grain yield of chickpea where the main factor was Mo application (0 and 241 g Mo ha^{-1}), secondary factor was B application with two levels (0 and 241 g B ha^{-1}) and tertiary factor was Zn (0, 120.50, 241.00, 482.00 and 964.00 g Zn ha^{-1}). Among them, B_1 (241.00 g ha^{-1}) produces the higher results regarding to yield (6.30 g plant^{-1}). Similarly, Kaisher *et al*. (2010) also found that B at 5 kg ha^{-1} significantly increased the seed yield of mungbean. Boron (0.2%) in green gram (Dixit and Elamathi, 2007); 1.5 kg B ha^{-1} in chickpea (Islam, 2005) and 4 kg borax ha^{-1} in black gram (Singh *et al*., 2002) were also showed higher grain yield where all the levels of B were statistically significant regarding to grain yield.

Table 20. Effect of Boron (B) fertilizers on various yield characters of black gram at harvest

Different levels of B (kg ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
0	1.42 d	3.57 d	4.98 e	28.41 d
0.5	1.53 b	3.68 b	5.20 c	29.33 bc
1.0	1.56 a	3.71 a	5.26 b	29.56 ab
1.5	1.57 a	3.72 a	5.29 a	29.68 a
2.0	1.49 c	3.65 c	5.14 d	29.08 c
SE value	**0.0025**	**0.0030**	**0.0029**	**0.1017**
Significance levels	**	**	**	**
CV (%)	**3.57**	**5.29**	**4.19**	**1.21**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Interaction effect between Zn and B

A highly significant variation was found due to the interaction effect of Zn and B on grain yield of black gram (Appendix XIV and Table 21). From the Table 19, it was found that the combined application of Zn @ 2.5 kg ha^{-1} and B @ 1.5 kg ha^{-1} produced significantly the highest grain yield (1.60 t ha^{-1}) which was statistically differed from other interactions but it was closely followed by the interactions of $Zn_{1.25}{\times}B_{1.0}$, $Zn_{1.25}{\times}B_{1.5}$, $Zn_{2.5}{\times}B_{0.5}$, $Zn_{2.5}{\times}B_{1.0}$, $Zn_{3.75}{\times}B_{1.0}$ and $Zn_{3.75}{\times}B_{1.5}$ (1.57, 1.59, 1.55, 1.58, 1.56 and 1.58 t ha^{-1}, respectively) whereas $Zn_{1.25}{\times}B_{1.0}$, $Zn_{1.25}{\times}B_{1.5}$, $Zn_{2.5}{\times}B_{1.0}$ and $Zn_{3.75}{\times}B_{1.5}$ were statistically identical. Among other interactions, the lowest grain yield (1.39 t ha^{-1}) was found from the interaction effect between control treatments of both fertilizers while it was statistically similar (1.40 t ha^{-1}) with the interaction effect of $Zn_{3.75}{\times}B_0$ and closely followed by the interactions of $Zn_{1.25}{\times}B_0$, $Zn_{1.25}{\times}B_{2.0}$ and $Zn_{2.5}{\times}B_0$ (1.424, 1.455 and 1.42 t ha^{-1}, respectively) but they were statistically significant (Table 19). Similarly, Quddus *et al*. (2011) found that the combined application of $Zn_{1.5}B_{1.0}$ produced significantly higher yield of mungbean (3058 kg ha^{-1}) and (2631 kg ha^{-1}) in the year 2008 and 2009, respectively. Valenciano *et al*. (2010) also showed that the highest seed yield of chickpea was obtained from the $Zn_4{\times}B_2{\times}Mo_2$ treatment (4.00 g $plant^{-1}$).

A similar finding was also obtained by Gupta *et al*. (2007) who found that the treatment combinations of $N_{22}P_{60}K_{60}S_{20}Zn_{15}B_5$ increased the yield higher yield which was 123% over the control.

4.3.6 Straw yield

Effect of Zinc (Zn)

Analysis of variance data regarding to straw yield showed significant variation due to the effect of Zn fertilizer (Appendix XIV and Table 19) where significantly the higher yield of straw (3.69 t ha^{-1}) was recorded from the Zn application @ 2.5 kg ha^{-1} while without Zn treatment observed the lower straw yield (3.62 t ha^{-1}). However, rest of the tow levels of Zn (Zn @ 1.25 and 3.75 kg ha^{-1}) noticed the statistically similar straw yield (3.66 and 3.66 t ha^{-1}, respectively). Similarly, Quddus *et al*., (2011) also found that the treatment combination of $N_{21}P_{23}K_{30}S_{18}Zn_2B_{1.5}$ produced significantly the highest average stover yield (4049 kg ha^{-1}).

Effect of Boron (B)

Straw yield affected significantly due to the effect of different doses of B fertilizer (Appendix XIV and Table 20). Among the B fertilizer doses, statistically the highest straw yield (3.72 and 3.70 t ha^{-1}) was obtained from the B application @ 1.50 and 1.0 kg ha^{-1}, respectively while the lowest straw yield (3.56 t ha^{-1}) was found in control treatment and it was statistically differed from other B doses (Table 18).

Interaction effect between Zn and B

Straw yield data affected significantly by the interaction effect of Zn and B fertilizer (Appendix XIV and Table 21). Among the interactions, the highest straw yield (3.75 t ha^{-1}) was found from the treatment combination of Z @ 2.5 kg ha^{-1} × B @ 1.5 kg ha^{-1} which was closely followed by the interactions of $Zn_{1.25}{\times}B_{1.0}$, $Zn_{1.25}{\times}B_{1.5}$, $Zn_{2.5}{\times}B_{0.5}$, $Zn_{2.5}{\times}B_{1.0}$, $Zn_{3.75}{\times}B_{1.0}$ and $Zn_{3.75}{\times}B_{1.5}$ (3.728, 3.743, 3.707, 3.738, 3.717 and 3.733 t ha^{-1}, respectively) whereas $Zn_{1.25}{\times}B_{1.0}$, $Zn_{1.25}{\times}B_{1.5}$, $Zn_{2.5}{\times}B_{1.0}$ and $Zn_{3.75}{\times}B_{1.5}$ were statistically identical. In contrast, the lowest straw yield (3.54 t ha^{-1}) was found from the treatment combinations of both control fertilizers while it was statistically identical (3.55 t ha^{-1}) with the interaction effect of $Zn_{3.75} \times B_0$ and closely followed by the interactions of $Zn_{1.25}$×B_0, $Zn_{1.25}$×$B_{2.0}$ and $Zn_{2.5}$×B_0 (3.57, 3.60 and 3.57 t ha^{-1}, respectively) but they were not statistically identical (Table 19). Stover yield showed significant variation and varied between 1,068 kg ha^{-1} in the control to 2,006 kg ha^{-1} under the treatment combination of $N_{22}P_{60}K_{60}S_{20}Zn_{15}B_5$ (Gupta *et al.*, 2007).

4.3.7 Biological yield

Effect of Zinc (Zn)

Analysis of variance data regarding to straw yield showed significant variation due to the effect of Zn fertilizer (Appendix XIV and Table 19) where significantly the higher yield of straw (3.69 t ha^{-1}) was recorded from the Zn application @ 2.5 kg ha^{-1} while without Zn treatment observed the lower straw yield (3.62 t ha^{-1}). However, rest of the tow levels of Zn (Zn @ 1.25 and 3.75 kg ha^{-1}) noticed the statistically similar straw yield (3.66 and 3.66 t ha^{-1}, respectively). Similarly, Dashadi *et al*. (2013) found that Zn applied as $ZnSO_4$: 0, 10 and 20 kg ha^{-1} whereas Zn applied to the soil, had a significant effect on biological yield. Similarly, Khorgamy and Farnia (2009) also reported the similar findings where Zn had significant effects on biological yield.

Effect of Boron (B)

Straw yield affected significantly due to the effect of different doses of B fertilizer (Appendix XIV and Table 20). Among the B fertilizer doses, statistically the highest straw yield (3.72 and 3.70 t ha^{-1}) was obtained from the B application @ 1.50 and 1.0 kg ha^{-1}, respectively while the lowest straw yield (3.56 t ha^{-1}) was found in control treatment and it was statistically differed from other B doses (Table 18).

Interaction effect between Zn and B

Straw yield data affected significantly by the interaction effect of Zn and B fertilizer (Appendix XIV and Table 21). Among the interactions, the highest straw yield (3.75 t ha^{-1}) was found from the treatment combination of Zn @ 2.5 kg ha^{-1} × B @ 1.5 kg ha^{-1} which was closely followed by the interactions of $Zn_{1.25}$×$B_{1.0}$, $Zn_{1.25}$×$B_{1.5}$, $Zn_{2.5}$×$B_{0.5}$, $Zn_{2.5}$×$B_{1.0}$, $Zn_{3.75}$×$B_{1.0}$ and $Zn_{3.75}$×$B_{1.5}$ (3.72, 3.74, 3.70, 3.73, 3.71 and 3.73 t ha^{-1}, respectively) whereas $Zn_{1.25}$×$B_{1.0}$, $Zn_{1.25}$×$B_{1.5}$, $Zn_{2.5}$×$B_{1.0}$ and $Zn_{3.75}$×$B_{1.5}$ were statistically identical. In contrast, the lowest straw yield (3.54 t ha^{-1}) was found from the treatment combinations of both control fertilizers while it was statistically identical (3.558 t ha^{-1}) with the interaction effect of $Zn_{3.75} \times B_0$ and closely followed by the interactions of $Zn_{1.25}{\times}B_0$, $Zn_{1.25}{\times}B_{2.0}$ and $Zn_{2.5}{\times}B_0$ (3.57, 3.60 and 3.57 t ha^{-1}, respectively) but they were not statistically identical (Table 19).

4.3.8 Harvest index (HI)

Effect of Zinc (Zn)

Harvest index was significantly elevated by the application of Zn fertilizer at harvest (Appendix XIV and Table 19). The maximum HI (29.47%) was obtained from the Zn @ 2.50 kg ha^{-1} treated plant of black gram which was statistically identical with the application of Zn @ 1.25 and 3.75 kg ha^{-1} (29.26 and 29.25%, respectively). As a result, rest treatment (Zn @ 0 kg ha^{-1} or control or untreated Zn) observed the lowest HI (28.86%). These results revealed that all the treatment (levels) of Zn were more efficient to produce better than control. Khorgamy and Farnia (2009) also reported the similar findings where Zn had significant effects on harvest index.

Effect of Boron (B)

A significant variation was experienced in respect of harvest due to different levels of B (Appendix XIV and Table 20). Among the different levels of B, B @ 1.5 kg ha^{-1} produced significantly the higher HI (29.68%) which was closely followed by B @ 1.0 kg ha^{-1} (29.56%) and statistically differed from other treatments. On the other hand, untreated plant of black gram noticed the lowest HI (28.41%) which was also statistically differed from other treatments. From the Table 18, it was also found that the HI significantly increased in increasing of B up to 1.5 kg ha^{-1} thereafter it decreased with the upper doses of B.

Table 21. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on various yield characters of black gram at harvest

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
0	0	1.40 j	3.55 j	4.95 k	28.27 j
0	0.5	1.48 f–h	3.63 f–h	5.12 g–i	28.99 d–i
0	1.0	1.49 e–g	3.64 e–g	5.13 f–h	29.02 d–h
0	1.5	1.50 d–g	3.65 d–g	5.16 fg	29.12 c–e–h
0	2.0	1.47 f–i	3.62 f–i	5.08 hi	28.91 e–j
1.25	0	1.42 ij	3.57 ij	4.99 jk	28.49 h–j
1.25	0.5	1.55 b–e	3.69 b–e	5.24 d	29.49 a–e
1.25	1.0	1.58 ab	3.73 ab	5.30 a–c	29.74 a–c
1.25	1.5	1.59 ab	3.74 ab	5.34 ab	29.86 ab
1.25	2.0	1.46 g–ij	3.61 g–j	5.06 i	28.75 f–j
2.5	0	1.43 h–j	3.58 h–j	5.01 j	28.53 g–j
2.5	0.5	1.56 a–d	3.71 a–d	5.26 cd	29.58 a–e
2.5	1.0	1.59 ab	3.74 ab	5.33 ab	29.82 ab
2.5	1.5	1.61 a	3.76 a	5.36 a	29.95 a
2.5	2.0	1.54 b–e	3.69 b–e	5.24 de	29.47 a–e
3.75	0	1.41 j	3.56 j	4.97 jk	28.35 ij
3.75	0.5	1.52 c–f	3.67 c–f	5.18 ef	29.26 b–f
3.75	1.0	1.57 a–c	3.72 a–c	5.29 b–d	29.66 a–d
3.75	1.5	1.58 ab	3.73 ab	5.32 a–c	29.78 a–c
3.75	2.0	1.51 d–g	3.66 d–g	5.17 fg	29.19 b–g
SE value		**0.0049**	**0.0061**	**0.0058**	**0.2034**
Significance level		**	**	**	*
CV (%)		**3.57**	**5.29**	**4.19**	**1.21**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Interaction effect between Zn and B

Analysis of variance data on HI affected significantly due to the interaction effect of Zn and B (Appendix XIV and Table 21). Among the interaction treatments, the higher HI (29.95%) was observed from the interaction effect of Zn @ 2.50 × B @ 1.50 kg ha^{-1} which was closely followed by $Zn_{1.25}{\times}B_{1.5}$, $Zn_{2.5}{\times}B_{1.0}$, $Zn_{1.25}{\times}B_{1.0}$, $Zn_{3.75}{\times}B_{1.5}$, $Zn_{3.75}{\times}B_{1.0}$, $Zn_{1.25}{\times}B_{0.5}$, $Zn_{2.50}{\times}B_{0.5}$, $Zn_{2.50}{\times}B_{2.0}$ (29.86, 29.82, 29.74, 29.78, 29.66, 29.49, 29.58 and 29.47%, respectively) whereas $Zn_{1.25}{\times}B_{1.5}$ and $Zn_{2.5}{\times}B_{1.0}$, $Zn_{1.25}{\times}B_{1.0}$ and $Zn_{3.75}{\times}B_{1.5}$, and $Zn_{1.25}{\times}B_{0.5}$, $Zn_{2.50}{\times}B_{0.5}$ and $Zn_{2.50}{\times}B_{2.0}$ were statistically identical regarding to HI. Among other interaction treatments, the lowest HI (28.27%) was taken from the interaction effect of $Zn_0{\times}B_0$ which was closely followed by $Zn_{3.75}{\times}B_0$,

$Zn_{1.25}$×B_0, $Zn_{2.5}$×B_0, $Zn_{1.25}$×$B_{2.0}$ and Zn_0×B_0 (28.35, 28.49, 28.53, 28.75 and 28.91%, respectively) whereas they are not statistically identical.

4.4 Effect of Zn and/or B on exchangeable nutrient content of grain

4.4.1 Total nitrogen content (%)

Effect of Zinc (Zn)

Nitrogen content of black gram grain in this study differs significantly due to the main effect Zn (Appendix XV and Table 22). Among them, N content of black gram grain had higher (3.99%) in those grains which were treated by Zn @ 2.5 kg ha^{-1} and the lower (3.64%) in untreated Zn of black gram grain. Table 22 also indicated that all the doses of Zn were statistically differ with each other at 5% level. These results also revealed that the Zn @ 2.50 kg ha^{-1} treated plant of black gram accomplish more nutrient from the soil which was helpful to get more N content in grain.

Effect of Boron (B)

Nitrogen content of black gram grain was significantly influenced due to the effect B (Appendix XV and Table 23). Among the Table 22, it was found that the 1.5 kg ha^{-1} B treated plant of black gram produces the more N in grain (4.13%) while less N content in grain (3.38%) was found from the control treated plant of black gram. Table 20, also revealed that all the B levels were statistically significant with each other at 5% level. Bharti *et al*. (2002) carried out a similar field experiment of Chickpea (cv. BG 256) in Bihar, India where they found that the N and B content increased with increasing B rates.

Interaction effect between Zn and B

Interaction effect between Zn and B was significantly affected on N content of black gram grain (Appendix XV and Table 24). From the Table 21, it was appeared that the highest N content of black gram grain (4.24%) was taken from Zn @ 2.50×B @ 1.50 kg ha^{-1} treated plant of black gram which was significantly differed from other interactions. On the other hand, the lowest N content of grain (3.30%) was found from the interaction effect of both control fertilizers which was also statistically differed from other interactions. However, it was statistically close with the interactions of $Zn_{3.75} \times B_0$ and $Zn_{1.25} \times B_0$ (3.36 and 3.42%, respectively) but they were not statistically identical.

4.4.2 Phosphorus content (ppm)

Effect of Zinc (Zn)

Available P of black gram grain was presented in the Table 22 which was significantly influenced by the effect of Zn (Appendix XV). The highest value of available P (0.5055 ppm) obtained in Zn @ 2.50 kg ha^{-1} while it was statistically close with Zn @ 1.25 kg ha^{-1} and the lowest available P (0.33 ppm) was found under untreated control treatment. Similarly, Khorgamy and Farnia (2009) found that Zn had significant effects on P concentration (grain).

Effect of Boron (B)

Statistically significant variation was also observed in P content of grain when different doses of B were applied in blackgram field (Appendix XV and Table 23). The P content ranged was from 0.40 to 0.48 ppm. Among the different doses of B, the highest P content (0.48 ppm) was recorded in Zn @ 2.50 kg ha^{-1} which was significantly close at 5% level with the application of Zn @ both 0.5 and 1.25 kg ha^{-1} where Zn @ 0.5 and 1.25 kg ha^{-1} were statistically identical to produced P content of grain. Similarly, the lowest P content (0.40 ppm) was taken under without B treated plant.

Interaction effect between Zn and B

Analysis of variance data regarding to P content was significantly influenced by the interaction effect of Zn and B fertilizer (Appendix XV and Table 24). Among the treatment combinations, the P content ranged was from 0.29 to 0.54 ppm whereas the highest P content (0.54 ppm) was recorded from the interaction treatment of $Zn_{2.50} \times B_{1.50}$ which was closely followed by $Zn_{1.25} \times B_{1.5}$, $Zn_{2.5} \times B_{0.5}$, $Zn_{2.50} \times B_{1.0}$, $Zn_{1.25} \times B_{1.0}$, $Zn_{3.75} \times B_{1.5}$, $Zn_{1.25} \times B_{0.5}$, $Zn_{1.25} \times B_{2.0}$, $Zn_{2.50} \times B_{2.0}$, $Zn_{3.75} \times B_{0.5}$ and $Zn_{3.75} \times B_{1.0}$ (0.52, 0.51, 0.52, 0.50, 0.50, 0.49, 0.48, 0.49, 0.48 and 0.49%, respectively) whereas $Zn_{1.25} \times B_{1.5}$, $Zn_{2.5} \times B_{0.5}$ and $Zn_{2.50} \times B_{1.0}$, $Zn_{1.25} \times B_{1.0}$ and

$Zn_{3.75}$×$B_{1.5}$, and $Zn_{1.25}$×$B_{0.5}$, $Zn_{1.25}$×$B_{2.0}$, $Zn_{2.50}$×$B_{2.0}$, $Zn_{3.75}$×$B_{0.5}$ and $Zn_{3.75}$×$B_{1.0}$ were statistically identical. Among other interactions, the lowest P content (0.29 ppm) was recorded from the interaction treatment of Zn_0×B_0 which was also statistically close to Zn_0 ×$B_{0.5}$ and Zn_0×$B_{2.0}$ where Zn_0 ×$B_{0.5}$ and Zn_0×$B_{2.0}$ were statistically identical.

4.4.3 Potassium content (ppm)

Effect of Zinc (Zn)

Potassium content of black gram grain varied significantly due to the effect of Zn (Appendix XV and Table 22). The highest K content (0.49 meq $100g^{-1}$) was obtained from the treated plant of Zn @ 2.50 kg ha^{-1} while it was statistically close with Zn @ 1.25 kg ha^{-1} (0.48) while comparatively lower K content (0.36 meq $100g^{-1}$) was found from the control or without Zn treated plant of black gram.

Effect of Boron (B)

Potassium content of black gram grain differed significantly due to the application of different doses of B fertilizer (Appendix XV and Table 23). The K content ranged was from 0.41 to 0.48 meq $100g^{-1}$ where the highest P content (0.48 meq $100g^{-1}$) was recorded in Zn @ 2.50 kg ha^{-1} which was closely followed by the application of Zn @ both 0.5 and 1.25 kg ha^{-1} (0.46 and 0.47 meq $100g^{-1}$, respectively) where Zn @ 0.5 and 1.25 kg ha^{-1} were statistically identical to produced K content of grain. In contrast, K lowest had lower (0.41 meq $100g^{-1}$) in untreated B plant.

Interaction effect between Zn and B

Potassium content of the black gram grain in the present study showed significantly variation due to the interaction effect between Zn and B application at different levels (Appendix XV and Table 24). Among the interaction treatments, P content had higher (0.53 meq $100g^{-1}$) in interaction treatment of $Zn_{2.50}$×$B_{1.50}$ which was closely followed by $Zn_{1.25}$×$B_{1.5}$, $Zn_{2.5}$×$B_{0.5}$, $Zn_{2.50}$×$B_{1.0}$, $Zn_{1.25}$×$B_{1.0}$, $Zn_{3.75}$×$B_{1.5}$, $Zn_{1.25}$×$B_{0.5}$, $Zn_{1.25}$×$B_{2.0}$, $Zn_{2.50}$×$B_{2.0}$, $Zn_{3.75}$×$B_{0.5}$ and $Zn_{3.75}$×$B_{1.0}$ (0.52, 0.50, 0.51, 0.50, 0.50, 0.48, 0.47, 0.49, 0.47 and 0.48 meq $100g^{-1}$, respectively) whereas $Zn_{1.25}$×$B_{1.5}$, $Zn_{2.5}$×$B_{0.5}$ and $Zn_{2.50}$×$B_{1.0}$, $Zn_{1.25}$×$B_{1.0}$ and $Zn_{3.75}$×$B_{1.5}$, and $Zn_{1.25}$×$B_{0.5}$, $Zn_{1.25}$×$B_{2.0}$, $Zn_{2.50}$×$B_{2.0}$, $Zn_{3.75}$×$B_{0.5}$ and $Zn_{3.75}$×$B_{1.0}$ were statistically identical. On the other hand, the lowest P content (0.32 meq 100g^{-1}) was recorded from the interaction treatment of $Zn_0 \times B_0$ which was closely followed by $Zn_0 \times B_{2.0}$.

Table 22. Effect of Zinc fertilizers on various nutrient content of black gram grain after harvest

Different levels of Zn (kg ha^{-1})	Nutrient content of grain of black gram			
	N	P	K	S
0	3.64 d	0.33 c	0.37 c	0.23 c
1.25	3.86 b	0.49 ab	0.49 ab	0.24 ab
2.5	3.99 a	0.51 a	0.49 a	0.25 a
3.75	3.74 c	0.48 b	0.47 b	0.24 bc
SE value	**0.0196**	**0.0015**	**0.0015**	**0.0011**
Significance levels	**	**	**	**
CV (%)	**1.83**	**1.36**	**0.94**	**0.84**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

Table 23. Effect of Boron fertilizers on various nutrient content of black gram grain after harvest

Different levels of B (kg ha^{-1})	Nutrient content of grain of black gram			
	N	P	K	S
0	3.38 e	0.41 c	0.41 c	0.22 d
0.5	3.85 c	0.46 ab	0.46 ab	0.24 bc
1.0	3.96 b	0.47 ab	0.47 ab	0.25 b
1.5	4.13 a	0.48 a	0.49 a	0.26 a
2.0	3.73 d	0.44 b	0.45 b	0.24 c
SE value	**0.0220**	**0.0017**	**0.0017**	**0.0013**
Significance levels	**	**	**	**
CV (%)	**1.83**	**1.36**	**0.94**	**0.84**

**= Significant at 1% level of probability
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

4.4.4 Sulphur content (ppm)

Effect of Zinc (Zn)

Analysis of variance data regarding to S content of blackgram grain was significantly influenced by the effect of Zn (Appendix XV and Table 22). Among the treatments, S content of grain had higher (0.24 ppm) which was closely followed by Zn @ 1.25 kg ha^{-1} (0.24 ppm) and the lowest content of S in grain (0.23 ppm) was control treatment.

Main effect of Boron (B)

A significant variation was also observed in S content of grain when different doses of B were affected in black gram field (Appendix XV and Table 20). The S content ranged was from 0.21 to 0.25 ppm where the higher S content was recorded in Zn @ 2.50 kg ha^{-1} and the lower S content was taken from control treatment.

Interaction effect between Zn and B

Analysis of variance data regarding to S content was significantly influenced by the interaction effect of both Zn and B fertilizer (Appendix XV and Table 21). Among the treatment combinations, the P content ranged was from 0.21 to 0.26 ppm whereas the highest S content (0.26 ppm) was recorded under $Zn_{2.50}\times B_{1.50}$ treatment which was closely followed by $Zn_{1.25}\times B_{1.5}$, $Zn_{2.5}\times B_{1.0}$, $Zn_{2.50}\times B_{0.5}$, $Zn_{1.25}\times B_{1.0}$ and $Zn_{3.75}\times B_{1.5}$ (0.26, 0.25, 0.25, 0.25 and 0.25 ppm, respectively) whereas $Zn_{1.25}\times B_{1.5}$ and $Zn_{2.5}\times B_{1.0}$ and $Zn_{1.25}\times B_{1.0}$ and $Zn_{3.75}\times B_{1.5}$ were statistically identical. Similarly, the lowest S content (0.21 ppm) was recorded under $Zn_0\times B_0$ treatment which was also statistically close to $Zn_{3.75}\times B_0$, $Zn_{1.25}\times B_0$, $Zn_{2.5}\times B_0$, $Zn_0\times B_{2.0}$ and $Zn_0\times B_{0.5}$ (0.21, 0.22, 0.22, 0.22 and 0.23 ppm, respectively) where $Zn_{1.25}\times B_0$ and $Zn_{2.5}\times B_0$ were statistically identical.

From the above results investigation of the present study, it was found that the studied black gram variety were significantly affected by the singly or combined application of Zn and B regarding to various morphological, growth, yield and yield attributing and quality characters of grain where Zn @ 2.5 kg ha^{-1} and B @ 1.5 kg ha^{-1} singly or their interactions were more efficient for getting the higher performance of those studied characters than that of other application of Zn and B. So, the application of Zn @ 2.5 kg ha^{-1} or B @ 1.5 kg ha^{-1} or their interaction effect would be optimum levels of them for maximizing the grain yield of black gram in the present study.

Table 24. Interaction effect of Zinc (Zn) and Boron (B) fertilizers on various nutrient content of black gram grain after harvest

Zinc levels (kg ha^{-1})	Boron levels (kg ha^{-1})	Nutrient content of grain of black gram			
		N	P	K	S
0	0	3.30 m	0.29 f	0.32 g	0.22 h
0	0.5	3.68 j	0.34 ef	0.38 f	0.23 d–h
0	1.0	3.79 g–j	0.35 e	0.39 ef	0.24 c–g
0	1.5	3.91 e–h	0.36 e	0.39 ef	0.25 b–d
0	2.0	3.53 k	0.33 ef	0.36 fg	0.23 e–h
1.25	0	3.42 k–m	0.45 cd	0.44c–e	0.22 f–h
1.25	0.5	3.88 e–i	0.49 a–d	0.49a–d	0.24 b–e
1.25	1.0	4.02 de	0.51 a–c	0.50 a–c	0.25 a–d
1.25	1.5	4.24 ab	0.53 ab	0.52 ab	0.27 ab
1.25	2.0	3.75 ij	0.48 a–d	0.48 a–d	0.24 c–f
2.5	0	3.45 kl	0.45 cd	0.45 c–e	0.22 f–h
2.5	0.5	4.06 cd	0.51 ab	0.51 ab	0.25 a–c
2.5	1.0	4.17 bc	0.53 ab	0.52 ab	0.26 ab
2.5	1.5	4.35 a	0.54 a	0.54 a	0.27 a
2.5	2.0	3.92 e–g	0.50 a–d	0.49 a–d	0.25 b–d
3.75	0	3.36 lm	0.44 d	0.44 de	0.22 gh
3.75	0.5	3.77 h–j	0.48 a–d	0.48a–d	0.24 c–f
3.75	1.0	3.87 f–i	0.49 a–d	0.49 a–d	0.24b–e
3.75	1.5	4.00 d–f	0.50 a–c	0.50 a–c	0.25 a–d
3.75	2.0	3.71 j	0.48 b–d	0.47 b–d	0.245 c–g
SE value		**0.0439**	**0.0033**	**0.0034**	**0.0026**
Significance level		*	**	*	*
CV (%)		**1.83**	**1.36**	**0.94**	**0.84**

** and *= indicate significant at 1% and 5% level of probability, respectively.
Figures followed by same letter(s) are statistically similar as per DMRT at 5%

So, I recommended that the application of Zn @ 2.5 kg ha^{-1} or B @ 1.5 kg ha^{-1} or their interaction would be further used for higher production of black gram under the AEZ–28.

CHAPTER V

SUMMARY AND CONCLUSION

The present experiment was conducted at the research field of the Department of Agronomy, Sher–e–Bangla Agricultural University (SAU), Sher–e–Bangla Nagar, Dhaka–1207 during the period from August, 2012 to December, 2012 to study on the performance of various morphological, growth, yield and yield attributing and seed quality of black gram as influenced by Zn and B fertilizers under the AEZ–28. The blackgram variety cv. BARI Mash–3 was used as planting materials for the present study. The present study was also consists of four levels of Zn (0, 1.25, 2.50 and 3.75 kg ha^{-1}) and five levels of B (0, 0.5, 1.0, 1.5 and 2.0 kg ha^{-1}) as soil application. The seeds of the variety were collected from the BARI, Joydebpur, Gazipur on 30 July, 2012. The experiment was laid out in two factors split-plot design with three replications and analysis was done by the MSTAT–C package program whereas means were adjudged by DMRT at 5% level of probability. Data were recorded on plant height, number of leaves plants $^{-1}$, number of branches plants $^{-1}$ and root length as morphological traits; LAI, TDM, AGR, RGR, CGR, number of pods $plant^{-1}$, pod length, number of seeds pod^{-1}, 1000–seed weight, grain yield, straw yield, biological yield and harvest index as yield and yield contributing traits and various nutrient content of black gram grain such as N, P, K and S as seed quality.

The results of the present study were obtained on various morphological, growth, yield and seed quality characteristics where all the studied traits were significantly influenced due to the singly or interaction effect of both Zn and B fertilizers while most of the characters were found to be the higher in Zn @ 2.50 and B 1.50 kg ha^{-1} soil application. As a result, tallest plant (52.28 and 52.00 cm), maximum leaves (117.30 and 117.80 $plant^{-1}$), maximum branches (4.07 and 5.42 $plant^{-1}$), longest root (9.62 and 9.57 cm), higher TDM (379.50 and 386.00 g $plant^{-1}$), maximum pods (48.99 and 51.62 $plant^{-1}$), longest pod (5.06 and 4.99 cm), maximum seeds (6.98 and 7.11 pod^{-1}), higher weight of 1000–grain (41.60 and 41.75 g), higher grain yield (1.54 and 1.57 t ha^{-1}), higher straw yield (3.69 and 3.72 t ha^{-1}), higher biological yield (5.23 and 5.29 t ha^{-1}) and highest HI (29.47 and 29.68%) were recorded under the soil application of Zn @ 2.50 kg ha^{-1} and B @ 1.50 kg ha^{-1}, respectively at harvest. However, maximum LAI at 50 DAS, AGR, RGR and CGR were obtained at the stage between 35–50 DAS than that of other growth stages of black gram while Zn @ 2.50 kg ha^{-1} and B @ 1.50 kg ha^{-1} were also more effective to produced higher growth of black gram than other Zn and B application and also over control. As a result, the higher LAI (1.49 and 1.52), AGR (10.40 and 10.68 g $plant^{-1}$ day^{-1}), higher RGR (4.53 and 4.65g g^{-1} day^{-1}) and higher CGR (0.31 and 0.32 g m^{-2} day^{-1}) were taken under the soil application treatment of Zn @ 2.50 kg ha^{-1} and B @ 1.5 kg ha^{-1}, respectively. Similar effect was also found in seed quality characters of black gram in the present study in case of the Zn @ 2.50 kg ha^{-1} and B @ 1.5 kg ha^{-1} further recorded the higher performance on seed quality of black gram. The maximum N, P, K and S content of grain had higher in Zn @ 2.5 kg ha^{-1} (4.98%, 0.50 ppm, 0.49 ppm and 0.24 ppm, respectively) and B @ 1.5 kg ha^{-1} (5.12%, 0.48 ppm, 0.48 ppm and 0.25 ppm, respectively). Among the all above characters were perform lower in untreated or control treatment of both fertilizer. As a result, shortest plant (45.33 and 46.32 cm), minimum leaves (116.10 and 114.30 $plant^{-1}$), minimum branches (4.06 and 3.60 $plant^{-1}$), shortest root (9.01 and 8.83 cm), lower TDM (349.10 and 329.10 g $plant^{-1}$), minimum pods (42.49 and 37.50 $plant^{-1}$), shortest pod (4.69 and 4.52 cm), minimum seeds (6.78 and 6.65 pod^{-1}), lowest weight of 1000–grain (40.54 and 40.19 g), lowest yield of grain (1.47 and 1.41 t ha^{-1}), straw (3.62 and 3.56 t ha^{-1}) and biological (5.08 and 4.97 t ha^{-1}) yield and lowest HI (28.86 and 28.41%) were found in without soil application of Zn and B (control treatment), respectively at harvest. Similarly, lower LAI (1.72 and 1.65) at 50 DAS, AGR (9.99 and 9.69 g $plant^{-1}$ day^{-1}), RGR (4.36 and 4.23 g g^{-1} day^{-1}) and CGR (0.29 and 0.29 g m^{-2} day^{-1}) at 35–50 DAS were further observed in control of both Zn and B fertilizers, respectively. However, absolute, relative and crop growth of black gram where lower at the stage between 5–20 DAS and thereafter it increase up to 35–50 DAS and further decline at 50–65 DAS. On the other hand, lower content of N (4.64 and 4.38%), P (0.33 and 0.40 ppm), K (0.36 and 0.41 ppm) and S (0.23 and 0.21 ppm) of black gram grain had also lower in control treatment of both fertilizers (Zn and B). These results showed that the application of Zn and B would be highly efficient to get higher performance of black gram under the AEZ–28 than control condition whereas Zn @ 2.5 and B @ 1.5 kg ha^{-1} always recorded the greater performance for its more capacity to supplying more nutrients in black gram plant from the soil.

Interaction effect between Zn @ 2.5 and B @ 1.5 kg ha^{-1} had also more significant effect on the above studied characters except pod length at every data recording stages. Among the interaction treatments effect, $Zn_{2.5}\times B_{1.5}$ (2.5 kg Zn ha^{-1} and 1.5 kg B ha^{-1}) recorded the greater results on plant height (55.31 cm), leaves (118.40 $plant^{-1}$), branches (5.55 $plant^{-1}$), root length (9.92 cm), TDM (403.60 g $plant^{-1}$), pods (55.20 $plant^{-1}$), seeds (7.26 $plant^{-1}$), 1000–seed weight (42.03 g), grain yield (1.60 t ha^{-1}), straw yield (3.75 t ha^{-1}), biological yield (5.36 t ha^{-1}) and harvest index (29.95%) at harvest (65 DAS). It ($Zn_{2.5}\times B_{1.5}$) was also showed the higher performance to obtained the nutrient content such N, P, K and S of grain (5.34%, 0.54, 0.53 and 0.26 ppm, respectively) after harvest. However, interaction effect between Zn @ 2.50 kg ha^{-1} and B @ 2.0 kg ha^{-1} noticed the longest pod (5.73 cm) at harvest. Among other interaction treatments, interaction of both control ($Zn_0\times B_0$) produced significantly the lower results on the above studied characters such as plant height (43.03 cm), leaves (113.70 $plant^{-1}$), branches (3.44 $plant^{-1}$), root length (8.57 cm), TDM (313.60 g $plant^{-1}$), pods (34.93 $plant^{-1}$), pod length (4.46 cm), seeds (6.60 $plant^{-1}$), 1000–seed weight (39.67 g), grain yield (1.40 t ha^{-1}), straw yield (3.54 t ha^{-1}), biological yield (4.94 t ha^{-1}) and harvest index (28.27%) at harvest (65 DAS). Nutrient content of black gram such N, P, K and S of grain had also lower (4.30%, 0.29, 0.32 and 0.21 ppm, respectively) in control interaction of both fertilizers after harvest.

From the above results of the present study, it was found that the application of Zn and B regarding to various morphological, growth, yield and yield attributing and quality characters of grain black gram were significantly affected where Zn @ 2.5 kg ha^{-1} and B @ 1.5 kg ha^{-1} singly or their interactions were more effective for obtaining the greater results of the studied whole characteristics of black gram comparatively than that of other application of Zn and B also over control. So, it could be concluded that the application of Zn @ 2.5 kg ha^{-1} or B @ 1.5 kg ha^{-1} or their interaction effect would be optimum level for maximizing the grain yield of blackgram in the present study under the Madhupur Tract (AEZ–28).

I recommended that the application of Zn @ 2.5 kg ha^{-1} or B @ 1.5 kg ha^{-1} or their interaction would be further used for getting the higher production of black gram under the region of AEZ–28. However, further investigation is suggested especially in the field before handed over the technology to the end users.

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APPENDICES

Appendix I. The morphological, physical and chemical properties of the experimental land

Morphological characteristics

Constituents	Characteristics
Location	Field Laboratory, Department of Agronomy, SAU, Dhaka
Soil Series	Tejgaon
Soil Tract	Madhupur
Land type	High
General soil type	Slightly acidic in reaction with low organic matter content
Agro–ecological one	"AEZ–28" of Madhupur Tract
Topography	Fairly level
Soil type and colour	Deep Red Brown Terrace Soil
Drainage	Moderate
Depth of inundation	Above the flood level
Drainage condition	Well drained

Physical properties of the soil

Constituents	Results
Particle size analysis	
Sand (%) (0.0–0.02 mm)	21.75
Silt (1%) (0.02–0.002 mm)	66.60
Clay (%) (<0.002 mm)	11.65
Soil textural class	Silty loam
Colour	Dark grey
Consistency	Grounder

Result obtained from the mechanical analysis of the initial soil sample done in the Soil Resources Development Institute (SRDI), Dhaka.

Chemical composition of the initial soil (0–15 cm depth)

Constituents	Results
Soil pH	5.8
Organic matter (%)	1.30
Total nitrogen (%)	0.10
Available phosphorus (ppm)	27
Exchangeable potassium (me/100 g soil)	0.12

Methods of analysis

Texture	Hydrometer methods
pH	Ptentiometric method
Organic carbon	Walkely–Black method
Total N	Modified kjeldhal method
Soluble P	Olsen method ($NAHCO^3$)
Exchangeable K	Flame photometer method (Ammonium)
Available sulphur	spectrophotometer

Result obtained from the mechanical analysis of the initial soil sample done in the Soil Resources Development Institute (SRDI), Dhaka.

Appendix II. Monthly air temperature, rainfall, relative humidity and sunshine hours during the growing season (November 2011 to June 2012)

Month	Year	*Air temperature (^{O}C)			**Rainfall (mm)	*Relative humidity (%)	** Sunshine (hrs)
		Maximum	Minimum	Average			
November	2011	29.63	16.67	23.51	00.00	83.10	265.80
December	2011	25.52	15.70	20.61	00.00	87.55	142.80
January	2012	24.92	13.46	19.19	Trace	86.16	160.40
February	2012	28.77	15.33	22.05	Trace	73.57	223.40
March	2012	30.93	18.95	24.94	18.1	75.16	202.10
April	2012	28.53	16.85	22.69	19.58	79.58	119.65
May	2012	27.15	15.99	21.57	23.21	81.62	101.41
June	2012	26.54	14.61	20.58	21.54	82.35	111.26
Average		**27.75**	**15.95**	**21.89**	**13.74**	**81.14**	**165.85**

* Monthly average and ** Monthly total

Source: Bangladesh Meteorological Department (Climate division), Dhaka.

Appendix III: Lay out of the experiment

$Zn_0 \times B_0 \times R_1$	$Zn_0 \times B_0 \times R_2$	$Zn_0 \times B_0 \times R_3$
$Zn_0 \times B_{0.5} \times R_1$	$Zn_0 \times B_{0.5} \times R_2$	$Zn_0 \times B_{0.5} \times R_3$
$Zn_0 \times B_{1.0} \times R_1$	$Zn_0 \times B_{1.0} \times R_2$	$Zn_0 \times B_{1.0} \times R_3$
$Zn_0 \times B_{1.5} \times R_1$	$Zn_0 \times B_{1.5} \times R_2$	$Zn_0 \times B_{1.5} \times R_3$
$Zn_0 \times B_{2.0} \times R_1$	$Zn_0 \times B_{2.0} \times R_2$	$Zn_0 \times B_{2.0} \times R_3$
$Zn_{1.25} \times B_0 \times R_1$	$Zn_{1.25} \times B_0 \times R_2$	$Zn_{1.25} \times B_0 \times R_3$
$Zn_{1.25} \times B_{0.5} \times R_1$	$Zn_{1.25} \times B_{0.5} \times R_2$	$Zn_{1.25} \times B_{0.5} \times R_3$
$Zn_{1.25} \times B_{1.0} \times R_1$	$Zn_{1.25} \times B_{1.0} \times R_2$	$Zn_{1.25} \times B_{1.0} \times R_3$
$Zn_{1.25} \times B_{1.5} \times R_1$	$Zn_{1.25} \times B_{1.5} \times R_2$	$Zn_{1.25} \times B_{1.5} \times R_3$
$Zn_{1.25} \times B_{2.0} \times R_1$	$Zn_{1.25} \times B_{2.0} \times R_2$	$Zn_{1.25} \times B_{2.0} \times R_3$
$Zn_{2.5} \times B_0 \times R_1$	$Zn_{2.5} \times B_0 \times R_2$	$Zn_{2.5} \times B_0 \times R_3$
$Zn_{2.5} \times B_{0.5} \times R_1$	$Zn_{2.5} \times B_{0.5} \times R_2$	$Zn_{2.5} \times B_{0.5} \times R_3$
$Zn_{2.5} \times B_{1.0} \times R_1$	$Zn_{2.5} \times B_{1.0} \times R_2$	$Zn_{2.5} \times B_{1.0} \times R_3$
$Zn_{2.5} \times B_{1.5} \times R_1$	$Zn_{2.5} \times B_{1.5} \times R_2$	$Zn_{2.5} \times B_{1.5} \times R_3$
$Zn_{2.5} \times B_{2.0} \times R_1$	$Zn_{2.5} \times B_{2.0} \times R_2$	$Zn_{2.5} \times B_{2.0} \times R_3$
$Zn_{3.75} \times B_0 \times R_1$	$Zn_{3.75} \times B_0 \times R_2$	$Zn_{3.75} \times B_0 \times R_3$
$Zn_{3.75} \times B_{0.5} \times R_1$	$Zn_{3.75} \times B_{0.5} \times R_2$	$Zn_{3.75} \times B_{0.5} \times R_3$
$Zn_{3.75} \times B_{1.0} \times R_1$	$Zn_{3.75} \times B_{1.0} \times R_2$	$Zn_{3.75} \times B_{1.0} \times R_3$
$Zn_{3.75} \times B_{1.5} \times R_1$	$Zn_{3.75} \times B_{1.5} \times R_2$	$Zn_{3.75} \times B_{1.5} \times R_3$
$Zn_{3.75} \times B_{2.0} \times R_1$	$Zn_{3.75} \times B_{2.0} \times R_2$	$Zn_{3.75} \times B_{2.0} \times R_3$

North

West East

South

Legend:

Treatments: 20 (Zinc: 4 × B: 5); Replication: 3 (Three); Number of pot: 60
Length of plot: 2.5 m; Width of a plot: 2.0 m; Area of a plot: 5.0 m^2
Row to row distance: 0.30 m; plant to plant distance: 0.10m

Appendix IV. Analysis of variance (mean square) for plant height of black gram at different days after sowing

Source of variation	Degrees of freedom	Plant height (cm) at different days after sowing			
		20	35	50	65
Replication	2	83.72	67.75	27.77	24.90
Factor A	3	30.38**	256.20**	200.87**	165.12**
Factor B	4	26.24**	84.62**	91.24**	58.47**
AB	12	1.23**	2.56**	6.76**	2.07**
Error	38	0.24	0.32	0.19	0.17

Appendix V. Analysis of variance (mean square) for number of leaves plant^{-1} of black gram at different days after sowing

Source of variation	Degrees of freedom	Number of leaves plant^{-1} at different days after sowing			
		20	35	50	65
Replication	2	0.73	5.89	13.95	23.33
Factor A	3	2.92**	2.78*	3.45*	3.69*
Factor B	4	3.97**	4.95**	33.58**	22.54**
AB	12	0.03**	0.03**	0.11*	0.06*
Error	38	0.004	0.47	1.26	2.21

Appendix VI. Analysis of variance (mean square) for number of branches plant^{-1} of black gram at different days after sowing

Source of variation	Degrees of freedom	Number of branches plant^{-1} at different days after sowing			
		20	35	50	65
Replication	2	0.61	0.63	1.80	3.22
Factor A	3	3.95**	4.69*	6.12**	1.35*
Factor B	4	4.19**	3.79**	6.41**	4.47**
AB	12	0.15**	0.15**	0.16**	0.04*
Error	38	0.005	0.003	0.022	0.018

** and *= indicate significant at 1% and 5% level of probability, respectively.
Factor A= Zn levels; Factor B= Boron levels

Appendix VII. Analysis of variance (mean square) for root length of black gram at different days after sowing

Source of variation	Degrees of freedom	Root length (cm) at different days after sowing			
		20	35	50	65
Replication	2	0.04	0.03	0.04	0.10
Factor A	3	0.47**	0.96**	1.20**	1.01**
Factor B	4	0.58**	1.20**	1.11**	0.94**
AB	12	0.00**	0.003**	0.02**	0.001**
Error	38	0.00	0.001	0.013	0.004

Appendix VIII. Analysis of variance (mean square) for leaf area index of black gram at different days after sowing

Source of variation	Degrees of freedom	Leaf area index (LAI) at different days after sowing			
		20	35	50	65
Replication	2	0.002	0.002	0.003	0.002
Factor A	3	0.007**	0.007**	0.007**	0.007**
Factor B	4	0.016**	0.020**	0.043**	0.028**
AB	12	0.000*	0.000*	0.000*	0.000*
Error	38	0.000	0.000	0.000	0.000

Appendix IX. Analysis of variance (mean square) for total dry matter of black gram at different days after sowing

Source of variation	Degrees of freedom	Total dry matter (TDM) at different growth stages				
		5	20	35	50	65
Replication	2	0.004	35.22	201.51	225.34	116.25
Factor A	3	2.58**	631.56**	987.27**	1680.04**	2437.23**
Factor B	4	8.25**	1065.29**	1770.26**	3706.97**	5701.26**
AB	12	0.005**	1.28**	6.04**	14.81**	13.47**
Error	38	0	0.682	1.224	3.239	1.1

** and *= indicate significant at 1% and 5% level of probability, respectively.
Factor A= Zn levels; Factor B= Boron levels

Appendix X. Analysis of variance (mean square) for absolute growth rate (AGR) of black gram at different days after sowing

Source of variation	Degrees of freedom	Absolute growth rate (g plant^{-1} day^{-1}) at different growth stages			
		5–20	20–35	35–50	50–65
Replication	2	0.25	0.12	0.05	0.02
Factor A	3	2.48**	0.20**	0.45**	0.32**
Factor B	4	3.94**	0.48**	1.63**	1.21**
AB	12	0.005*	0.01**	0.04**	0.07*
Error	38	0.003	0.002	0.006	0.001

Appendix XI. Analysis of variance (mean square) for relative growth rate (RGR) of black gram at different days after sowing

Source of variation	Degrees of freedom	Relative growth rate (g g^{-1} day^{-1}) at different growth stages			
		5–20	20–35	35–50	50–65
Replication	2	0.024	0.001	0.009	0.004
Factor A	3	0.47**	0.04**	0.09**	0.06**
Factor B	4	0.75**	0.09**	0.31**	0.23**
AB	12	0.001*	0.002**	0.007**	0.014**
Error	38	0.001	0.0001	0.001	0.000

Appendix XII. Analysis of variance (mean square) for crop growth rate (CGR) of black gram at different days after sowing

Source of variation	Degrees of freedom	Crop growth rate (g m^{-2} day^{-1}) at different growth stages			
		5–20	20–35	35–50	50–65
Replication	2	0.002	0.015	0.000	0.000
Factor A	3	0.003**	0.03**	0.00**	0.00**
Factor B	4	0.007**	0.051**	0.001**	0.001**
AB	12	0.002**	0.003**	0.00**	0.00**
Error	38	0.001	0.0001	0.000	0.000

** and *= indicate significant at 1% and 5% level of probability, respectively.
Factor A= Zn levels; Factor B= Boron levels

Appendix XIII. Analysis of variance (mean square) for different yield contributing characters of black gram at harvest

Source of variation	Degrees of freedom	Pod length (cm)	Number of seeds pod^{-1}	Number of pods $plant^{-1}$	Thousand–seed weight (g)
Replication	2	3.613	0.191	0.021	3.432
Factor A	3	129.60**	0.39*	0.12**	3.34**
Factor B	4	350.69**	0.44*	0.38**	4.57**
AB	12	3.38**	0.13*	0.005**	0.09*
Error	38	0.01	0.15	0.001	0.242

Appendix XIV. Analysis of variance (mean square) for different yield characters of black gram at harvest

Source of variation	Degrees of freedom	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	0.003	0.003	0.005	1.089
Factor A	3	0.01**	0.01**	0.06**	0.96**
Factor B	4	0.05**	0.046**	0.19**	3.03**
AB	12	0.002**	0.002**	0.006**	0.10**
Error	38	0.00	0.00	0.00	0.12

Appendix XV. Analysis of variance (mean square) for various nutrient content of black gram grain after harvest

Source of variation	Degrees of freedom	Nutrient content of			
		N	P	K	S
Replication	2	0.23	0.002	0.002	0.001
Factor A	3	0.33**	0.10**	0.05**	0.001**
Factor B	4	0.94**	0.01**	0.01**	0.002**
AB	12	0.01*	0.000**	0.00*	0.00*
Error	38	0.006	0.00	0.00	0.00

** and *= indicate significant at 1% and 5% level of probability, respectively.
Factor A= Zn levels; Factor B= Boron levels