GROWTH AND YIELD ATTRIBUTES OF RICE AS INFLUENCED BY ZINC AND BORON

A THESIS

BY

MD. SHAHADAT HOSSAIN

Student no. 1605004

Session: 2016-2017

Semester: January-June, 2017

MASTER OF SCIENCE

IN

AGRONOMY

DEPARTMENT OF AGRONOMY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY

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DEDICATED

TO MY

BELOVED PARENTS

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June 2017 *The Author*

Growth and yield attributes of rice (*Oryza sativa* L.) as influenced by Boron and Zinc

ABSTRACT

The experiment was conducted at the research field, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh during January to April, 2017. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The experiment was consisted of two factors viz. factor A: B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1}, and Factor B: Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, and Zn_4 = 20 kg Zn ha^{-1}. Data were recorded on different growth and yield contributing parameters. Most of the parameters showed significant difference among the treatment. Results indicated that the highest plant height (92.91 cm), panicle length (28.30 cm), number of filled grain $panicle^{-1}$ (186.1), number of total grain $panicle^{-1}$ (203.1), grain yield (4.93 t ha^{-1}), and harvest index (35.69%) was recorded from B_3Zn_3. Whereas the highest values of number of non-effective tiller $hill^{-1}$ (8.25) and number of un-filled grain $panicle^{-1}$ (31.00) were recorded from the treatment combination of 0 kg B ha^{-1} and 0 kg Zn ha^{-1} i.e. B_1Zn_1 treatment. At 50, 60 and 70 DAT, the highest grain growth rate (0.029, 0.032 and 0.0390 g) was found from the treatment combination of B_3Zn_3 (10 kg B ha^{-1} and 15 kg Zn ha^{-1}), whereas the lowest grain growth rate (0.011, 0.019 and 0.0130g) was observed from the treatment combination of B_1Zn_1 (0 kg B ha^{-1} and 0 kg Zn ha^{-1}) at same DAT. The treatment combination (B_3Zn_3) performed better for increasing the grain growth and yield of *Tia* rice.

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CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal crops of the world, grown in wide range of climatic zones. Rice is being the primary food source for more than one-third of the world's population (Shaiful *et al.*, 2009). Geographical and agro-climatic conditions of Bangladesh are favorable for rice cultivation. Bangladesh is the 4th largest country of the world next to China, India and Vietnam in respect to rice production (BBS, 2016) where about 80% of the total cultivable land is used for rice production. Rice is the staple food for about 156 million people of the country. Fertilizers are indispensable for crop production system of modern agriculture. Today inorganic fertilizers, hold the key to success for increased crop productivity under Bangladesh agriculture, being responsible for about 60% of the total production (FRG, 2012). In past, only three primary nutrients viz. N, P and K along with one secondary nutrient S are commonly used in Bangladesh. The importance of micronutrient nutrition of crops was almost overlooked. However, some micronutrients are essential those play a significant role in crop nutrition which finally leads to healthy growth and increased yield. Crops require a sufficient supply of essential mineral elements for optimal growth and final harvest in terms of crop yield. An insufficient availability of essential nutrients (micro and macro) may cause stunted growth and limits the crop productivity. Different micronutrients have the contribution to grain growth of rice. Zinc (Zn) is an exceptional micronutrient regarding its relevance in biological systems because it is the only micronutrient represented in all classes of enzymes. After nitrogen, phosphorus and potassium widespread Zinc deficiency has been found responsible for yield reduction in rice (Fageria *et al.*, 2002). Zinc is essential in protein synthesis and gene expression in plants (Cakmak, 2000). It has been estimated that about 10% of proteins in biological systems need Zn for their structural and functional integrity (Andreini *et al.*, 2006). Applying Zn fertilizers in the soil increases dry matter, grain yield and grain Zn concentration in rice (Shehu and Jamala, 2010). Sowing rice seeds with high Zn content (mixing seed in Zn powder) was found to result in a rapid and better germination, greater root length and better shoot growth (Slaton *et al.*, 2001). Rice is one of the highly sensitive crops to Zinc deficiency, yields are often reduced and Zn concentrations in grains are often low when Zn is in short supply to the crop. Zinc deficiency affects several biochemical processes in rice plant, such as cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation and membrane integrity and growth (IRRI, 2000). Application of Zinc fertilizer is essential in keeping sufficient amount of available Zn in soil solution, maintaining adequate Zinc transport to the seeds during reproductive growth stage and thus increase crop yield (Sudha and Stalin, 2015).

Boron (B) improves the pollen vitality of rice flowers (Garg *et al.*, 1979). Boron is responsible for better pollination, seed setting and grain formation in different rice varieties (Aslam *et al.*, 2002; Rehman *et al.*, 2012), making it more important during the reproductive stage as compared to the vegetative stage of the crop. Boron is very important in cell division and seed formation (Vitosh *et al.*, 1997). Boron is concerned with precipitating excess cations, buffer action, regulatory effect on other nutrient elements etc., development of new cells in meristematic tissue, translocation of sugars, starches, phosphorus etc., essential for cell wall formation. Boron deficiency occurs under moister stress and dry condition which cause reduced plant height (Zu *et al.*, 2012). Plants fail to produce panicles if they are affected by B deficiency at the panicle initiation stage, tips of emerging leaves are white and rolled. Rate of water adsorption and carbohydrate translocation restricted due to Boron deficiency. The deficiency symptoms of Boron in rice include thinner stems, shorter and fewer tillers, and failure to produce viable seeds. Boron deficient stems and leaves are brittle whereas B sufficient stems and leaves are flaccid (Dunn *et al.*, 2005). B deficiency is commonly prevailing in crops that are grown in soils with higher carbonates, lower organic matter, and higher p^H (Lindsay, 1991; Rashid, 1996). Boron is a micronutrient essential for normal healthy plant growth and development of reproductive tissues. *Tia* is a newly released boro rice variety from ACI Seed Company, Bangladesh for boro season but effects of micronutrients like Zinc and Boron on this variety are not yet studied in Bangladesh. Therefore, the present investigation was carried out with the following objectives

i. To study the effect of Zinc and Boron on the growth and yield potentiality of Tia rice and
ii. To identify the effective levels of Zinc and Boron for growth and yield for the maximization of that variety.

CHAPTER II

REVIEW OF LITERATURES

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REVIEW OF LITERATURE

Rice is the main food crop in Bangladesh. In this chapter to present a brief review of research works in relation to the effect of Zinc and Boron on growth, yield components, yield and nutrients composition of rice has been presented below.

2.1 Effect of Boron on growth and yield of rice

A field experiment was undertaken at Nuclear Institute of Agriculture (NIA) Shah (2016). Result showed that both varieties responded differently to B rates. The variety Sarshar produced the highest paddy yield (5691 kg ha^{-1}) @ 1.5 kg B ha^{-1} and was 18% greater than control, Shandar produced the highest yield (6075 kg ha^{-1}) at a rate of 1.0 kg B $ha^{-1}$and was 5% greater yield than control. B accumulation increased in paddy and straw with the increasing B rates.(to evaluate the Boron (B) requirement (0, 0.5, 1.0, 1.5 and 2.0 kg ha^{-1}) of two non-aromatic rice varieties of Sarshar and Shandar.)

A field experiment was conducted by Guru *et al.* (2016) to know the effect of Boron (B) on reproductive growth and yield attributes of seven rice genotypes of IET 20979, IET 21007, IET 21106, IET 21114, IET 21519, IET 21540 and Rasi (check) against four levels of B spray{ (control, 0.2 ppm (0.375 kg B ha^{-1}), 0.4 (0.75 kg B ha^{-1}) and 0.8 ppm (1.5 kg B ha^{-1})} given at flowering stage. They observed that IET 20979 and IET 21519 responded more positively to Boron application at 0.4 ppm, this increase in grain yield was mainly due increase in pollen viability and stigma receptivity.

A field experiment was conducted by Sarwar *et al.* (2016) to see the impact of Boron fertilization with basal and foliar application in water saving rice cultivation systems. Boron, applied as basal (3 kg borax/acre) and foliar (2% Boron) at different growth stages in rice under various rice cultivation systems of flooded rice, intermittent flooding and drying, and aerobic rice. They observed that Boron fertilization with basal and foliar application technique resulted in improved crop performance in all cultivation systems.

A field experiment was conducted by Ali *et al.* (2016) to evaluate the effect of B on yield and yield components of rice. The experiment was laid out in randomized complete block design (RCBD) with six B foliar application rates (0, 5, 10, 15, 20 and 25 mg L^{-1}). The results illustrated a significant effect of B foliar application on number of grains panicle^{-1}, number of filled grains and grain yield. The highest grain yield (352 g m^{-2}) was recorded in 20 mg L^{-1} foliar application. Detrimental effects of the highest B application on yield components were observed. Rehman *et al.* (2014) conducted an experiment to evaluate the influence of B on leaf elongation, tillering, water relations, yield and B grain enrichment of rice cultivars *Super Basmati* and *Shaheen Basmati*. They observed that B improved leaf elongation, tillering, leaf chlorophyll contents, water relations, grain yield, yield traits and B grain contents with simultaneous decrease in panicle sterility.

A field experiment was carried out by Hyder *et al.* (2012) to investigate the effect of different levels of Boron (0.5, 1.0, 1.5 and 2.0 kg ha^{-1}) on growth, yield and ionic concentration of rice directly sown on raised beds under saline sodic soils (ECe =5.32 dS m^{-1}, pH=8.52 and SAR=18.87). They observed that tillering, number of grains spike^{-1}, 1000- grain weight and paddy yield significantly increased at different levels of B.

Lordkaew *et al.* (2013) conducted an experiment with three rice varieties (KDML105, CNT1, SPR1) to know effects of B deficiency grain weight was strongly depressed by B deficiency ranging from 28% in SPR1 to 79% in CNT1, and yield was much lower in the cool season than in hot season plantings.

A field experiment was conducted by Safiq and Maqsood (2010) on a sandy clay loam soil to monitor the response of rice crop to model based applied B fertilizer. They reported that grains per panicle, 1000 grain weight and paddy yield responded positively to fertilizer B but vegetative growth i.e. plant height, tillering and total biomass did not respond significantly to B application.

A field experiment with two factorial RCBD design replicated thrice was conducted by Guru *et al.* (2012) to study the effect of B foliar application on performance of ten genotypes includes seven varieties (IET 20979, IET 21007, IET 21106, IET 21114, IET 21519, IET 21540, Rasi) and three hybrids (PA 6201, PA 6444, PHB 71) the found that B improves high, low density grains and reduces the chaffy grains. Long duration genotypes (IET 20979, IET 21513, IET 21540, PA 6444 and PHB 71) produced the maximum number of low density grains, and short duration genotypes (Rasi and PA 6201) produce maximum number of high density grains.

Saleem *et al.* (2011) observed that residual B from borax significantly increased plant height, number of tillers and panicles per plant, number of grains per panicle and weight of 1000 grain of rice.

A field experiment was conducted by Shah *et al.* (2011) with four B levels 0, 0.5, 0.75 and 1.0 kg ha^{-1} with two rice varieties viz. Khushboo-95 and Mehak to determine the effect of different levels of B on the yield and yield components of rice. They reported that number of productive tillers/plant, panicle length and 1000 grain weight and number of grains/panicle in Khushboo-95 were significantly enhanced upto 1.0 kg B ha^{-1}.

Khan *et al.* (2007) conducted a field experiment during 2004-05 on wheat and rice to study the response of Boron application in wheat-rice system. Two levels of Boron viz., 1 and 2 kg ha^{-1} with control in a permanent layout. Boron application significantly influenced wheat grain yield ranged from 2.70 to 3.49 t ha^{-1} giving the highest increase of 19.9% over control from 1.0 kg ha^{-1}. plant height number of tillers m^{-2}, spike m^{-2}, spike length, and 1000-grain weight of wheat were also significantly different from control for the same treatment. Paddy yield was also significantly affected by Boron application, which ranged from 3.51 to 6.11 t ha^{-1}. The highest yield was obtained from 2 kg B ha^{-1} when applied to both crops. The number of spikes m^{-2}, spike length, plant height and 1000-grain weight of paddy were significantly affected over control. The direct application of 1 and 2 kg B ha^{-1} gave an increase of 59.6 and 62.1%, cumulative application of 1 and 2 kg B ha^{-1} increased the paddy yield by 61.1 and 74.1%, while residual application of 1 and 2 kg B ha^{-1} increased the yield by 36.8 and 48.8% over control, respectively. The direct application of 2 kg B ha^{-1} to each crop could be recommended for economical yield. Boron concentration in the leaves of wheat and rice was significantly affected by the application of Boron that ranged from10.37-14.91 and 3.52-5.81 mg kg^{-1}, respectively. Similarly the Boron concentration in soil was also significantly affected by Boron content in wheat and rice and ranged from 0.18-0.51 and 0.17-0.61 mg kg^{-1}, respectively. The highest concentration in leaf and soil in wheat was found from 2 kg ha^{-1}, while cumulative application of 2 kg ha^{-1} proved to be the highest in both crops.

Dunn *et al.* (2005) found that soil sampling and testing for Boron is currently not a common practice for farmers producing rice (*Oryza sativa* L.) in south-eastern United States. A field research in Missouri showed that rice yields were the greatest when soil B levels were 0.25 to0.35 ppm by hot water extraction method. In 2000, rice receiving soil-applied B produced significantly greater yields than rice with foliar-applied B and rice with no B applied. In 1999 and 2001, there was no significant difference between yields obtained with foliar or soil B applications.

Muralidharan and Jose (1995) carried out a field experiment and observed that rice grain yield increased (5% over control) due to Boron application.

Hossain (1996) carried out an experiment on integrated nutrient management for BR11 rice at BAU farm and showed that B concentration in grain and straw increased when Boron was applied to soil.

2.1 Effect of Zinc on growth and yield of rice

A field experiment was carried out by Alam and Kumar (2015) to find out the effect of Zinc (0, 05, 10 and 20 kg/ha $ZnSO_4$) on growth and yield of Rice var. Pusa Basmati-1 in Saran district of Bihar, India and they observed the highest yield traits and yield were when 10 kg $ZnSO_4$/ha was applied.

A field experiment was conducted by Sudha and Stalin (2015) to study the effect of Zinc (no Zn and 100 kg/ha $ZnSO_4.7H_2O$ at basal plus foliar application of 0.5 per cent $ZnSO_4.7H_2O$ at flowering, milk and dough stages of rice) application on yield, quality and grain Zinc content of different rice genotypes. They reported that application of Zinc significantly increased plant height, number of productive tillers, filled grains per panicle, panicle length and 1000 grain weight as compared to NPK fertilization alone.

Beutler *et al.* (2014) conducted an experiment with six Zn doses (0, 50, 100, 200, 400 and 800 g ha^{-1}, using two Zn sources such as $ZnSO_4.7H_2O$ and $ZnCl_2$) in rice (Puitá INTA Cl) to evaluate the effect of dose, source and application time of Zinc (Zn) on germination, cold test (germination), seed physiological potential and flooded rice yield. They observed that treating rice seeds with Zn did not change the germination rate, seedling emergence or grain yield upto 1600 g ha^{-1}.

An experiment was conducted at Agronomic Research Area, University of Agriculture, Faisalabad by Qaisrani (2011) to evaluate the effect of different methods and timing of Zinc application on growth and yield of rice and observed that Zinc application increased the crop growth rate of rice.

Kabeya and Shankar (2013) reported that rice (*Oryza sativa*) is the worlds' most important cereal and potentially an important source of Zinc (Zn) for people who eat mainly rice. Zinc deficiency being a major constraint to reduce the potential yield of rice. To improve Zn delivery by rice, plant Zn uptake and internal allocation need to be better investigated. Field experiments were carried out to find out the effect of three different levels of Zinc on rice Zinc contrasting lines, high Zinc groups and low Zinc groups. The experiments revealed that increased Zn supply induced increased plant Zn uptake rate throughout the crop development in both high Zinc groups and low Zinc groups. The highest effect was observed when treated with 30 kg $ZnSO_4$ ha^{-1} irrespective of Zinc groups. However, high Zinc groups showed better uptake ability in Zinc content and overall performance in growth characteristics.

The study was conducted by Boonchuay *et al*. (2012) with eight times foliar Zn treatments of 0.5% Zinc sulfate ($ZnSO_4{\cdot}7H_2O$) in rice at different growth stages and observed that foliar Zn increased paddy Zn concentration only when applied after flowering, with larger increases when applications were repeated.

An experiment was carried out by Ilma *et al*. (2012) with three Zinc levels (0, 2 and 4 kg ha^{-1}) in rice to evaluate the Zinc content in different plant parts, and the highest Zinc content in grain, Zinc uptake ingrain and straw, and nitrogen uptake in grain were observed with 4 kg Zn ha^{-1}.

Hydroponically studies were conducted by Asadi *et al.* (2012) in rice seedlings (*Oryza sativa* L., cv. TaromHashemi) under 4 Zinc levels (0.5, 5, 50 and 100 µM $ZnSO_4$). It was resulted that Zn decreased Zn-TF, increased Zn accumulation in roots. Addition of Zn from 0.5 to 5 µM in nutrient solution increased shoot length, plant dry weight, superoxide dismutase (SOD) and decreased ascorbate peroxidase (APX) and guaiacol peroxidase (GPX) while addition of Zn from 5 to 100 µM had the reverse effects.

Muthukumararaja and Sriramachandrasekhara (2012) reported that Zinc deficiency in flooded soil is impediment to obtain higher rice yield. Zinc deficiency is corrected by application of suitable Zinc fertilizer. The results revealed that rice responded significantly to graded dose of Zinc. The highest grain (37.53 g pot^{-1}) and straw yield (48.54 g pot^{-1}) was noticed at 5 mg Zn kg^{-1}, which was about 100 and 86% greater than control (no Zinc), respectively. The highest Zinc concentration and uptake in grain and straw and DTPA-Zn at all stages was noticed at 7.5 mg Zn kg^{-1}. The linear regression analysis showed grain Zinc concentration and grain Zn uptake caused 89.64 and 89.01% variation in rice yield. Similarly, the linear regression analysis of DTPA-Zn caused 98.31, 96.34 and 93.12% variation in yield of rice at tillering, panicle initiation and harvesting stages, respectively. The agronomic, physiological and agro physiological apparent recovery and utilization efficiencies was the highest at lower level of Zinc application and decreased with Zn doses.

An experiment was conducted by Mustafa *et al*. (2011) at agronomic research area, University of Agriculture, Faisalabad to evaluate the effect of different methods and timing of Zinc application on growth and yield of rice. Experiment was comprised of eight treatments viz., control, rice nursery root dipping in 0.5% Zn solution, $ZnSO_4$ application at the rate of 25 kg ha^{-1} as basal dose, foliar application of 0.5% Zn solution at 15, 30, 45, 60 and 75 days after transplanting. The maximum productive tillers per m^2 (249.80) were noted with basal application at the rate of 25 kg ha^{-1} $ZnSO_4$ (21% Zn) and minimum (220.28) were recorded with foliar application at 60 DAT @ 0.5% Zn solution. Zinc application methods and timing had significantly pronounced effect on paddy yield. The maximum paddy yield (5.21 t ha^{-1}) was achieved in treatment Zn_2 (Basal application at the rate of 25 kg ha^{-1} of $ZnSO_4.7H_2O$) and minimum paddy yield (4.17 t ha^{-1}) was noted in Zn_7 (foliar application at 75 DAT @ 0.5% Zn solution).

A field investigation was undertaken by Veeranagappa (2010) to study the effect of Zinc enriched compost on soil properties, yield and uptake of nutrients by rice (*Oryza sativa* L.). There were eleven treatment combinations comprising of recommended dose of compost, NPK fertilizers, $ZnSO_4$ and Zinc enriched compost. The experiment was laid out in randomized complete block design and replicated thrice. Significantly higher growth and yield attributes were recorded in package of practice followed by NPK + Zn-E compost at 15 and 10 kg ha^{-1}. Grain yield and straw yield were also superior in the same treatments. The same trend was noticed for uptake of primary, secondary and micronutrients.

Naik and Das (2007) reported that rice is mostly transplanted under puddled low land soil conditions in India, where Zinc (Zn) deficiency is a common problem. The objective of this study was to find out the efficacy of split application of Zn on growth and yield of rice in an inceptisol. The split application of Zn as $ZnSO_4.7H_2O$ performed better than its single basal application, while the split application of Zn-EDTA did not show any significant difference on yield and yield components of rice over its single basal application. Zn-EDTA was found to be better for growth and yield of rice among the two sources of Zn. The soil application of Zn at 1.0 kg ha^{-1} as Zn-EDTA (T_7) recorded the highest grain yield of 5.42 t ha^{-1}, filled grain percentage of 90.2%, 1000-grain weight of 25.41 g and number of panicles m^{-2} of 452. The Zn content of grain and straw were also found to be maximum in the treatment T_7 i.e. 38.19 and 18.27 mg Zn kg^{-1}, respectively. Linear regression studies indicated that grain yield of rice is significantly influenced by Zn content of grain, Zn content of straw and DTPA extractable Zn content of soil at the level of 95.96, 96.74 and 95.57, respectively.

A pot experiment was conducted by Khan *et al.* (2007) at Faculty of Agriculture Gomal University, Pakistan to evaluate the effect of different levels of Zinc application on the yield and growth components of rice at eight different soil series. Zn as $ZnSO_4.7H_2O$ (21% Zn) was applied @ 0, 5, 10 and 15kg ha^{-1} along with the basal doses of 120 kg N, 90 kg P_2O_5 and 60 kg K_2O ha^{-1}. They had grown 30 days old four seedlings of rice cv. IRRI-6. It was resulted that increasing levels of Zn in these soil series significantly influenced yield and yield components of rice and application of 10 kg Zn ha^{-1} appeared to be an optimum dose for rice crop in these soil series.

A study was carried out by Cheema *et al.* (2006) to evaluate the effect of four Zinc levels on the growth and yield of coarse rice cv. IR-6 at Faisalabad, Pakistan. Four Zinc levels *viz.*, 2.5, 5.0, 7.5 and 10 kg $ZnSO_4$ ha^{-1} increased yield and yield component as compared with control. Plant height, number of tillers $hill^{-1}$, panicle bearing tillers, number of primary and secondary spikelets, panicle size, 1000-grain weight, paddy and straw yield and harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Singh *et al.* (2012) conducted field experiments at main campus of ICAR Research Complex of Eastern Region Patna with four levels of both nutrients i.e. sulphur and Zinc. Based on three years of experimentation, results revealed that rice plant height is significantly influenced by sulphur and Zinc. Tallest plant (101.7 cm) was recorded at maturity with application of 6 kg Zn ha^{-1}.

A field experiment was conducted by Dixit *et al.* (2012) to study the effect of sulphur and Zinc on yield, quality and nutrient uptake by hybrid rice grown in sodic soil. They reported that increasing doses of sulphur and Zinc significantly increased their uptake by hybrid rice crop and the interaction effect of sulphur and Zinc was found non-significant and finally, the highest grain and straw yields were recorded with application of 40 kg S and 10 kg Zn ha^{-1}.

An experiment was conducted by Boonyanitipong *et al.* (2011) to investigate the effects of Zinc oxide nano-particles (nano-ZnO) on rice (*Oryza sativa* L.) roots. They observed that Nano-ZnO stunted roots length and reduced number of roots.

Tarafder *et al.* (2008) conducted an experiment with eight treatments of sulphur and Zinc for rice. The experiment was laid out in a randomized complete block design with three replications. In Boro rice, growth and yield attributes, grain and straw yields responded significantly to S and Zn. The average grain yield varied from 3.51 to 5.27 t ha^{-1} over the treatments. In case of T. aman rice, the grain and straw yields responded significantly to S and Zn.

An experiment was conducted by Rahman *et al.* (2008) at Bangladesh Agricultural University, Mymensingh farm during 2004 in Boro season to evaluate the effect of S and Zn on rice (cv. BRRI dhan29). There were seven treatments viz. S_0Zn_0, $S_{10}Zn_0$, $S_{20}Zn_0$, $S_0Zn_{1.5}$, $S0Zn_3$, $S_{10}Zn_{1.5}$ and $S_{20}Zn_3$. The subscripts of S and Zn represent the dose in kg ha^{-1}. The highest grain (5.76 t ha^{-1}) and straw (7.32 t ha^{-1}) yields were recorded from $S_{20}Zn_3$ treatment (100% recommended dose). The control produced the lowest grain yield with 4.35 t ha^{-1} as well as the lowest straw yield with 5.47 t ha^{-1}. The application of both S and Zn fertilizers significantly increased S and Zn contents as well as their uptake over control.

Singh and Singh (2004) observed that Zinc sulfate was the superior source compared to others. Zinc application increased chlorophyll and increased the tissue concentration of Zn, Ca, Mg, K and P, whereas decreased Na content. Zinc modified the elemental composition of plant tissues favorably and thereby accelerated plant growth and yield.

2.3 Combined effect of Zinc and Boron on rice yield attributes and yield

A field experiment in a calcareous soil was conducted by Sarwar *et al.* (2013) in which basal application of Boron & Zinc alone, or in combination, was undertaken in rice grown aerobically (T_1), flooded for the entire growth period (T_2) or flooded for two weeks after transplanting, given supplemental irrigation up to panicle initiation and then flooded from panicle initiation to physiological maturity (T_3). The study showed that application of Zinc alone or in combination with Boron enhanced chlorophyll contents in T_2 similar to T_3 while the crop grown in aerobic condition (T_1) had significantly lower chlorophyll content.

Tavares *et al.* (2013) conducted an experiment to assess physiological quality of seeds and the initial growth of lowland rice seedlings, cv. PUITA INTA-CL, treated with a product based on Zinc, Boron and molybdenum. The following treatments were used: 0 (control), 50, 100, 150 and 200 mL.100 kg^{-1} seed. It was concluded that treatment of rice seeds with product containing Zinc, Boron and molybdenum up to the dosage tested of 200 mL.100 kg^{-1} seed does not influence germination, first count of germination, and dry phytomass of aerial parts and roots; however, negatively influences seedling length. In addition, it also promotes greater plant height, higher leaf area, higher production of dry phytomass of seedlings, and increase on the growth rate, until 42 DAE.

A farm experiment was conducted by Aref (2011) with corn grown on Zinc (Zn) and Boron (B) deficient soil was conducted to study the effect of Zn and B on the concentration and total uptake of N, P and K in corn grain at Fars Province of Iran. Treatments included five levels of Zn (0, 8, 16 and 24 kg ha^{-1} Zn added to the soil and Zn foliar spray with a 0.5 percent concentration) and four levels of B (0, 3 and 6 kg ha^{-1} B added to the soil and B foliar spray with a 0.3 percent concentration) in a completely randomized block design. The results of this study showed that the application of B at low Zn levels had no significant effect on the NPK concentrations in the grain, but at high Zn levels, increased NPK concentrations in the grain. Therefore, a high Zn content in the soil helped increasing the N, P and K concentrations and P uptake in the grain by B application i.e. at high Zn levels, there was a synergism between B, N, P and K.

Islam (1992) carried out a long-term experiment of wheat-mungbean- T. Aman cropping pattern at Wheat Research Centre (WRC), Dinajpur (1988-90). He found that Zn and B application had beneficial effect on that pattern. Residual effects of Zn, S and B showed pronounced effect in increasing grain yield of rice.

Sur and Ali (1992) in alluvial soils of North Bengal and red lateritic soil of South Bengal (India) reported that B and Zn applications significantly increased yield of Kharif rice. Rates of 25 to 37.5 kg ha^{-1} $ZnSO_4$ and 10 to 15 kg ha^{-1} borax were recommended for economic returns.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The materials and methods were used for conducting the experiment has been presented in this chapter. It includes a short description of the location of experimental site, soil and climate condition of the experimental area, materials used for the experiment, design of the experiment, data collection and data analysis procedure.

3.1 Experimental site

The experiment was conducted at Agronomy Research Field of Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh during December to May 2016. It was located in $25^{o}37'$ N latitude and $88^{o}39'$ E longitude at an elevation of 37 m above the mean sea level on the eastern bank of the river Punarvhaba.

3.2 Soil used for experiment

The collected soil belongs to The Old Himalayan piedmont plain (AEZ-1). The soil of the experimental plot was collected from 0-15 cm depth from HSTU research field. The soil samples were analyzed in the soil resource development institute (SRDI), Dinajpur. The soil samples used in the plots were dried, powdered and mixed thoroughly. The result of soil analysis has been presented in Appendix II.

3.3 Crop

The crop under study was rice and the variety used was *Tia*, a popular variety of ACI seed company. The seeds used in this study were certified seeds. Life cycle of this variety is 120 days including seedling age.

3.4 Treatments of the experiment

The experiment consisted of two factors:

Factor A: Boron

i. B_1: 0 kg/ha

ii. B_2: 5 kg/ha

iii. B_3: 10 kg/ha

iv. B_4: 15 kg/ha

Factor B: Zinc

i. Zn_1: 0 kg/ha

ii. Zn_2: 10 kg/ha

iii. Zn_3: 15 kg/ha

iv. Zn_4: 20 kg/ha

There were 16 (4 × 4) treatments combination such as B_1Zn_1, B_1Zn_2, B_1Zn_3, B_1Zn_4, B_2Zn_1, B_2Zn_2, B_2Zn_3, B_2Zn_4, B_3Zn_1, B_3Zn_2, B_3Zn_3, B_3Zn_4, B_4Zn_1, B_4Zn_2, B_4Zn_3 and B_4Zn_4. Every treatment including control received a recommended and equal amount of N, P, K and S.

3.5 Land preparation

The land was prepared on the 30th December, 2016. The land was prepared by repeated ploughing by a power tiller. Weeds and stubbles of the previous crop were collected and removed from the field. After leveling, the experimental plots were laid out as per treatments and design.

3.6 Experimental design

The experiment was laid out in a randomized complete block design. There were 16 treatment combinations, each treatment replicated three times. The treatments were randomly distributed to the plots within a block. Thus, the number of plots was 3×16 = 48. The unit plot size was 10 m^2.

Block 1	Block 2	Block 3
1	12	7
4	13	8
2	14	9
6	15	10
14	16	11
9	1	12
11	2	13
3	3	14
5	4	15
10	5	16
7	6	1
12	7	2
16	8	3
8	9	4
15	10	5
13	11	6

Fig 1. Layout of the experiment

3.7 Fertilizer application

Total amount of TSP, MoP, gypsum, Zinc sulphate, boric acid and one third of urea were applied during final land preparation. The doses of urea, TSP, MoP and gypsum were 237, 170, 40, 89 kg ha^{-1}, respectively. Micronutrient (Zinc and Boron) rates have been mentioned in the section 3.5. Urea was applied as top dressing into two equal splits at tillering stage, and at panicle initiation stage.

3.8 Transplanting of seedlings

Thirty five days old seedlings were transplanted in the experimental plots on the 3rd December, 2016. A distance of 20cm from plant to plant and 20cm from row to row was maintained. Two seedlings were transplanted in each hill.

3.9 Intercultural operations

Intercultural operations were done to ensure normal growth of the crop. Plant protection measures were followed as and when necessary. The following intercultural operations were done.

3.10 Irrigation

Necessary irrigations were provided to the plots as and when required during the growing period of rice crop.

3.11 Weeding

The plots were infested with some common weeds, which were removed by uprooting them from the field three times during the cropping season.

3.12 Insect and pest control

There was no infection of diseases in the field but rice bug (*Leptocoriza acuta*) was observed in the field and used Malathion 57EC @ 1 L ha^{-1} to control rice bug.

3.13 Harvesting

The crop was harvested at maturity on the 20th April, 2017. The harvested crop from each plot was bundled separately and brought to the threshing floor. The crops were threshed, cleaned and processed. Then weights (g) of both sun dried grain and straw were recorded for every plot and converted in to kg ha^{-1}.

3.14 Data recorded

3.14.1 Plant height (cm)

The height of plant was recorded in centimeter (cm) at the time of harvesting. The height was measured from the ground level to the tip of the panicle/flag leaf. Data were recorded as the average of five plants selected at random from the inner rows of each plot.

3.14.2 Number of tillers $hill^{-1}$

The number of tillers $hill^{-1}$ was counted at the time of harvesting. Data on tillers $hill^{-1}$ were counted from five selected hills and average value was recorded.

3.14.3 Effective tillers $hill^{-1}$

The total number of effective tillers $hill^{-1}$ was counted as the number of panicle bearing tiller during flowering. Data on effective tillers $hill^{-1}$ were counted from five selected hills and average value was recorded.

3.14.4 Non-effective tillers $hill^{-1}$

The total number of non-effective tillers $hill^{-1}$ was counted as the number of non-panicle bearing tillers and were counted from five selected hills and average value was recorded.

3.14.5 Panicle length (cm)

The length of panicle was measured in cm with a meter scale from five selected plants and the average value was recorded as per plant.

3.14.6 Number of panicle m^{-2}

Number of panicle m^{-2} was recorded.

3.14.7 Grain growth rate

Grain growth rate was taken at 10 days interval after heading.

Grain growth rate= Grain weight/total number of grain

3.14.8 Filled grains panicle^{-1}

The total numbers of filled grain was collected randomly from selected five plants of a plot on the basis of grain in the spikelet and then average numbers of filled grains panicle^{-1} was recorded.

3.14.9 Unfilled grains panicle^{-1}

The total numbers of unfilled grain was collected randomly from selected five plants of a plot on the basis of not grain in the spikelet and then average numbers of unfilled grains panicle^{-1} was recorded.

3.14.10 Total number of grains hill^{-1}

The total numbers of grain was collected randomly from selected five plants of a plot by adding filled and unfilled grain and then average numbers of grains panicle^{-1} was recorded.

3.14.11 Weight of 1000-grain (g)

One thousand grains were counted randomly from the total cleaned harvested grains and then weighed in grams and recorded.

3.14.12 Grain yield (tha^{-1})

Grains obtained from each unit plot were sun-dried and weighed carefully. The dry weight of grains of central 1 m^2 area and five sample plants were added to the respective unit plot yield to record the final grain yield plot^{-1} and finally converted to ton hectare^{-1} (t ha^{-1}).

3.14.13 Straw yield (tha^{-1})

Straw obtained from each unit plot were sun-dried and weighed carefully. The dry weight of straw of central 1 m^2 area and five sample plants were added to the respective unit plot yield to record the final straw yield plot^{-1} and finally converted to ton hectare^{-1} (t ha^{-1}).

3.14.14 Harvest index (%)

The harvest index was calculated with the following formula:

Harvest index (%) = (Grain yield/Biological yield) $\times 100$

3.15 Statistical Analysis

The data obtained for different characters were statistically analyzed to observe the significant difference among the treatment. The mean values of all characters were calculated and analysis of variance was performed. The significance of difference among treatments means were estimated by Duncan's Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out the influence of Boron and Zinc on the growth, yield traits and yield of boro rice variety *Tia*. Data on different growth parameter and yield of rice were recorded. The results have been presented and discussed with the help of table and graphs and possible interpretations are given under the following headings:

4.1 Plant height (cm)

4.1.1 Effect of Boron

The plant height of Tia rice variety was significantly influenced by Boron application (Fig. 2). The tallest plant (89.07cm) was obtained from B_3 (10 kg ha^{-1}) followed by B_2 (5 kg ha^{-1}), whereas the shortest (84.86 cm) was at B_1 (0 kg ha^{-1}). Soil favours the plant growth through sufficient supply of Boron that is very important for adequate rice development.

Boron is associated with the development of cell wall and cell differentiation and hence, helps in root elongation and shoot growth of plant. The application of B helps to activate the synthesis of tryptophan and precursor of indole acetic acid (IAA) which is responsible for stimulation of plant growth. Khan *et al.* (2006) and Shah *et al.* (2011) reported that Boron application to rice might increase plant height by enhancing growth rate and development of root and shoot. Khan *et al*. (2007) found similar result in case of plant height. They observed that plant height was significantly influenced by B application range from 3.51 to 6.11 t ha^{-1}.

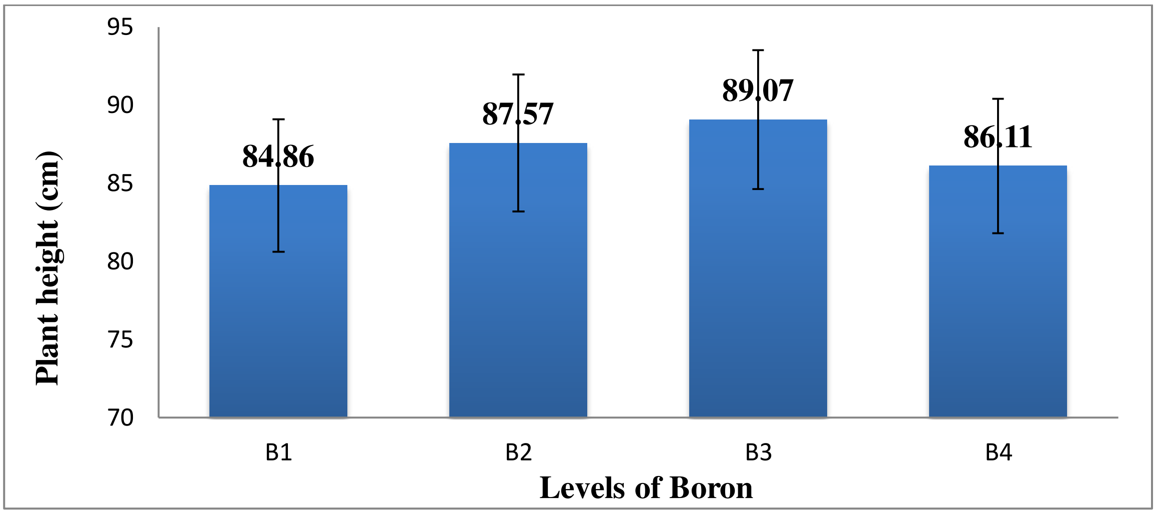


Fig. 2. Effect of Boron on plant height of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg Bha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15kg B ha^{-1})

4.1.2 Effect of Zinc

Significant variation was observed on plant height of the variety *Tia* due to the application of various level of Zinc (Fig. 3). It was resulted that the tallest plant (88.99 cm) was found in Zn_3 (15 kg ha^{-1}) while, the shortest plant (84.87 cm) was achieved from Zn_1 (0 kg ha^{-1}). The result obtained from the present study was conformity with the findings of Ullah *et al.*, (2001). They found that soil application of Zinc sulphate increased plant height. Cheema *et al.* (2006) also reported that plant height showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

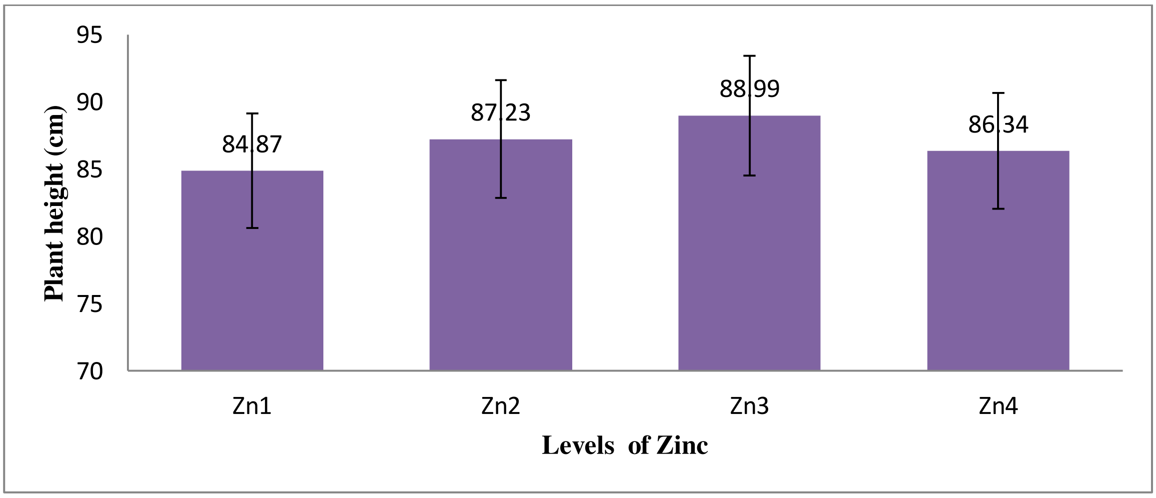


Fig. 3. Effect of Zinc on plant height of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4= 20 kg Zn ha^{-1})

4.1.3 Combined effect of Zinc and Boron

The combined effect Boron and Zinc showed significant variation on plant height of Tia rice (Table 1). The tallest plant (92.91 cm) was obtained from B_3Zn_3 and the shortest plant (82.13 cm) was achieved by B_1Zn_1. This might be due to the auxin metabolism and increased photosynthetic rate by interaction of residual amount of Zinc and Boron in soil with applied. Boron and Zinc application significantly increased plant height as mentioned by Siddika (2013).

4.2 Number of effective tillers hill^{-1}

4.2.1 Effect of Boron

There was significant variation in effective tillers hill^{-1} of Tia rice due to application of different levels of Boron (Fig. 4). Effective tillers hill^{-1} (9.89) was the maximum at B_3 which was closely followed (8.7.69) by B_2, whereas the minimum number (5.1) was found from B_1 treatment. The increase in number of effective tillers plant^{-1} may be due to fulfillment of Boron deficiency at appropriate time. Ashraf (2004), and Yu and Bell (2002) reported that number of productive tillers, grain weight and ultimately yield of paddy cultivars increased with Boron application. Ali *et al*. (1996) observed an increase in productive tillers plant^{-1} in rice with Boron application.

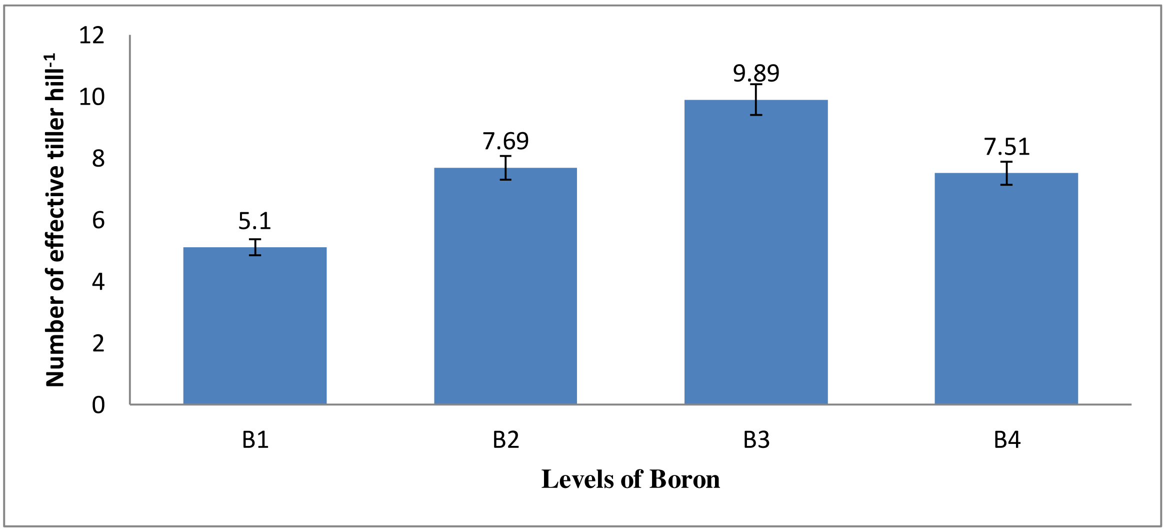


Fig. 4. Effect of Boron on number of effective tiller hill^{-1} *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.2.2 Effect of Zinc

The number of effective tillers hill^{-1} of Tia rice was significantly influenced by different levels of Zinc (Fig. 5). The maximum number of effective tillers hill^{-1} (8.85) was recorded from Zn_3 and the minimum number (7.87) was observed from Zn_1. Zinc application activates and increases tillering capacity in rice due to improved enzymatic activity. Ullah *et al.* (2001). Cheema *et al.* (2006), and Babiker (1986) observed that productive tillers were significantly affected by rice cultivars and $ZnSO_4$ rates. They also reported that 50 kg ZnSO4 ha^{-1} especially for nursery grown rice, was the most effective and economic rate for improving grain yield and its components.

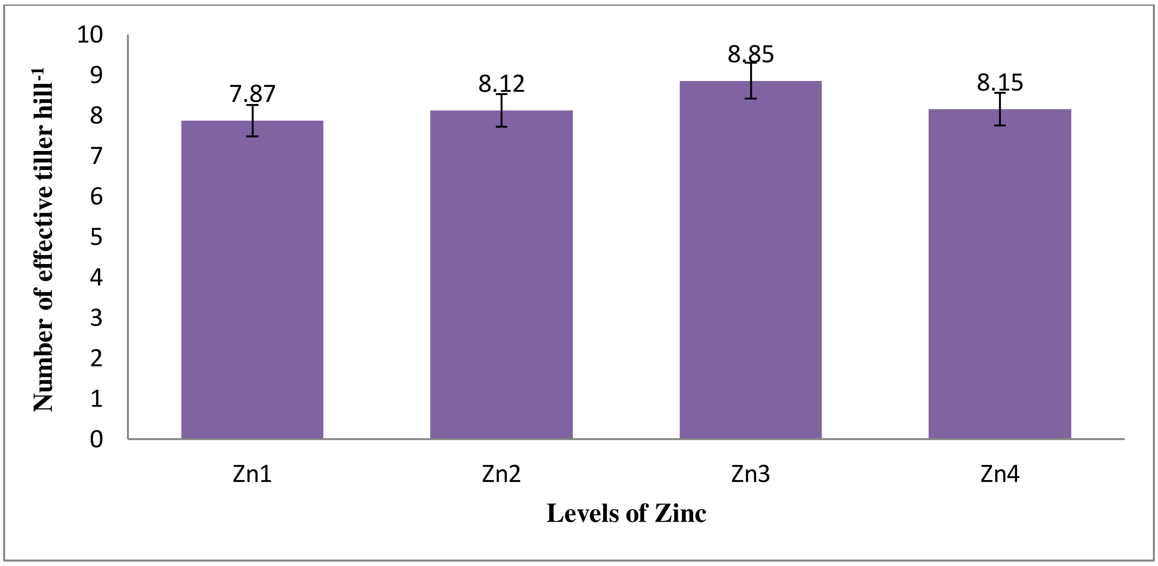


Fig. 5. Effect of Zinc on number of effective tillers hill^{-1} of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.2.3 Combined effect of Zinc and Boron

The number of effective tiller hill^{-1} was significantly varied by combined effect of Boron and Zinc (Table 1). Result showed that the highest number of effective tiller hill^{-1} (14.89) was obtained from B_3Zn_3. On the other hand, the lowest number of effective tiller hill^{-1} (2.56) was found in B_1Zn_1. Kusutani *et al.* (2000), and Dutta *et al.* (2002) reported that revealed that influence of the treatment on fat cultivars produces higher number of effective tillers/hill and highest number of grains per panicle.

4.3 Number of non-effective tillers hill^{-1}

4.3.1 Effect of Boron

Significant variation was observed in terms of number of non-effective tiller hill^{-1} by application of Boron for Tia rice (Fig. 6). The results revealed that the highest number of non-effective tiller hill^{-1} (7.22) was found in B_0 (Control) whereas the lowest number of non-effective tiller hill^{-1} (4.20) was obtained from B_3 (10 kg B ha^{-1}).

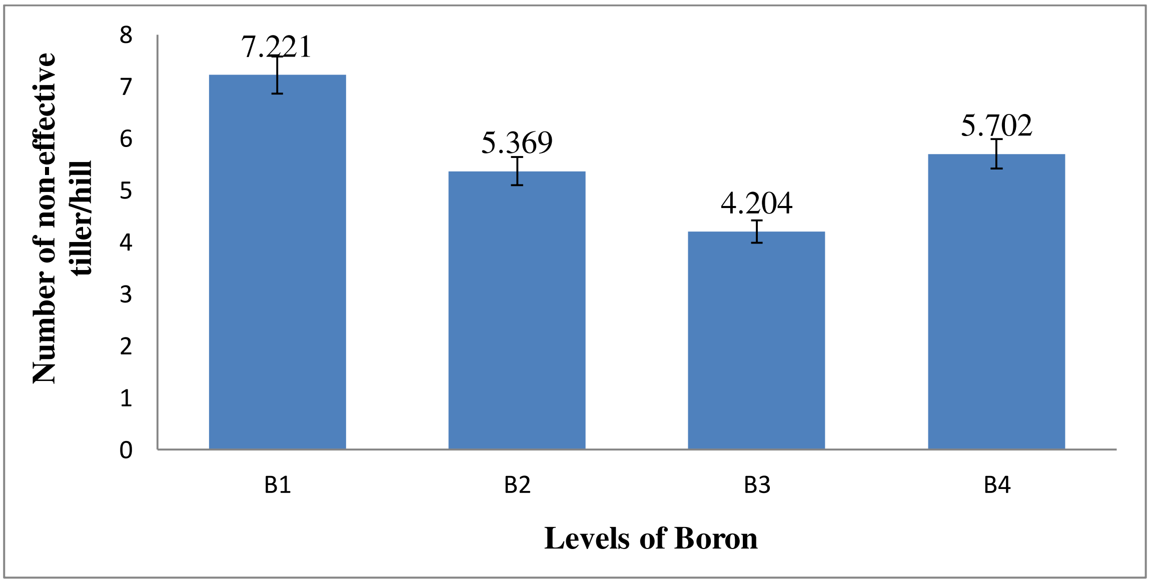


Fig. 6. Effect of Boron on number of non-effective tiller hill^{-1} *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.3.2 Effect of Zinc

Application of Zinc significantly influenced number of non-effective tiller hill^{-1} of Tia rice (Fig. 7). Result showed that the maximum non-effective tiller hill^{-1} (5.58) was found in Zn_1 (0 kg ha^{-1}), while the minimum non effective tiller hill^{-1} (5.11) was found in Zn_3 (15 kg ha^{-1}). Babiker (1986).

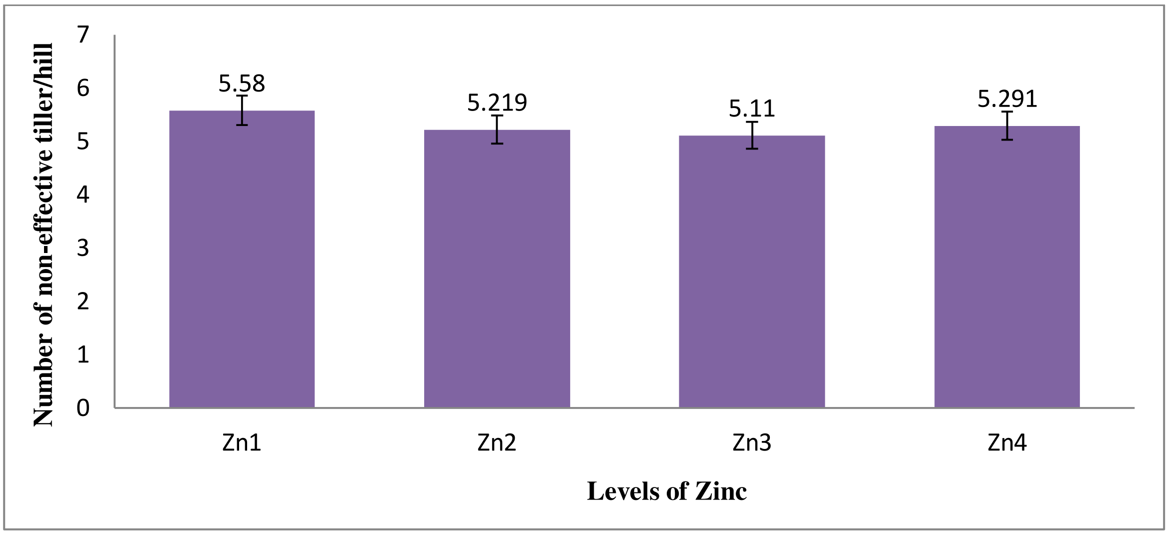


Fig. 7. Effect of Zinc on number of non-effective tiller ha^{-1} of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha_{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.3.3 Combined effect of Boron and Zinc

The combined effect of different levels of Boron and Zinc showed significant differences for number of non-effective tiller $hill^{-1}$ of *Tia* rice (Table 2). The highest number of non-effective tiller $hill^{-1}$ (8.25) was recorded from the treatment combination of B_1Zn_1 which was statistically similar with B_1Zn_4 and B_1Zn_3, whereas the minimum number (2.31) was found in B_3Zn_3. The number of non-effective tillers/hill was reduced due to the application of Boron and Zinc as reported by Dutta *et al.* (2002).

Table 1. Effect of Boron and Zinc on plant height (cm), number of effective tillers hill^{-1} and number of non-effective tillers hill^{-1} of *Tia* rice

Treatments	Plant height (cm)	Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}
B_1Zn_1	82.13 k	2.56 f	8.25 a
B_1Zn_2	84.35 hij	8.02 cd	7.22 b
B_1Zn_3	86.11 fg	9.07 b	8.11 a
B_1Zn_4	83.90 j	8.13 c	8.00 ab
B_2Zn_1	85.34 gh	7.35 cd	7.25 b
B_2Zn_2	90.23 bc	8.24 c	3.10 fg
B_2Zn_3	86.14 fg	9.20 b	5.11 de
B_2Zn_4	88.57 d	8.13 b	6.11 c
B_3Zn_1	84.90 hij	9.11 b	5.55 cd
B_3Zn_2	91.32 b	11.12 ab	3.15 f
B_3Zn_3	92.91 a	14.89 a	3.00 g
B_3Zn_4	87.17 ef	9.00 b	3.10 f
B_4Zn_1	84.13 ij	8.00 cd	5.65 cd
B_4Zn_2	90.04 c	7.04 d	5.29 de
B_4Zn_3	88.12 de	8. 02cc	6.13 c
B_4Zn_4	85.10 ghi	5.13 e	4.55 e
LSD	1.154	0.723	0.785
Level of significance	**	*	**
CV (%)	8.76	11.64	18.54

4.4 Number of total tillers hill^{-1}

4.4.1 Effect of Boron

Different levels of Boron showed significant differences on number of total tillers hill^{-1} of Tia rice (Fig. 8). The maximum number of total tillers hill^{-1} (14.09) was obtained from B_3, whereas the minimum number (12.32) was attained from B_1. Dell and Huang (1997) reported that Boron application increases leaf expansion and thereby the photosynthetic capacity of plants.

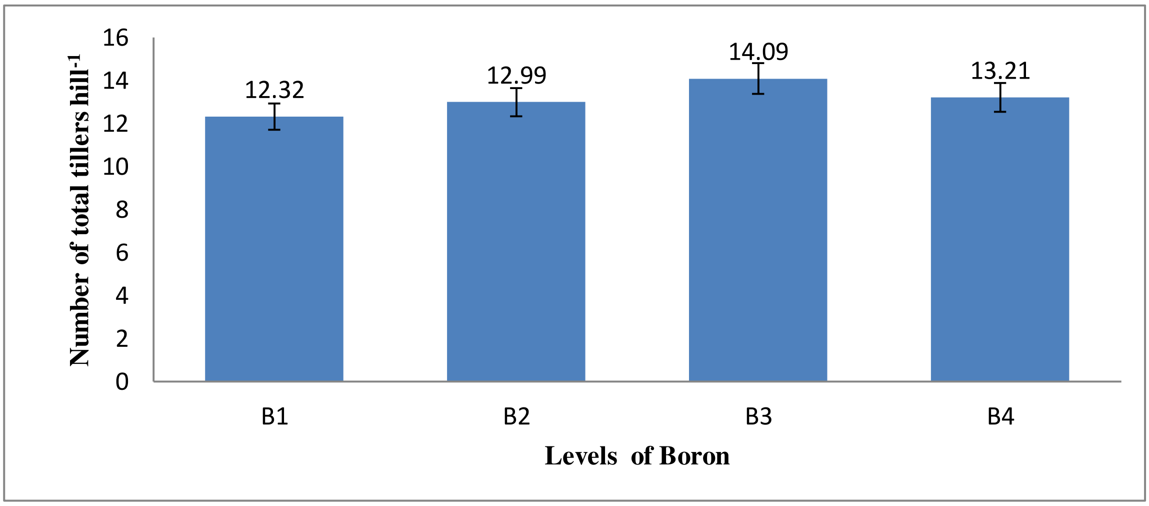


Fig.8. Effect of Boron on number of total tillers hill^{-1} *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.4.2 Effect of Zinc

Number of total tillers hill^{-1} of *Tia* rice was influenced significantly due to the different levels of Zinc (Fig. 9). The maximum number of total tillers hill^{-1} (14.80) was examined from Zn_1 and the minimum number (12.53) from Zn_2 (Fig. 9). IRRI (2000) indicated that Zinc application activates and increases tillering capacity in rice due to improved enzymatic activity.

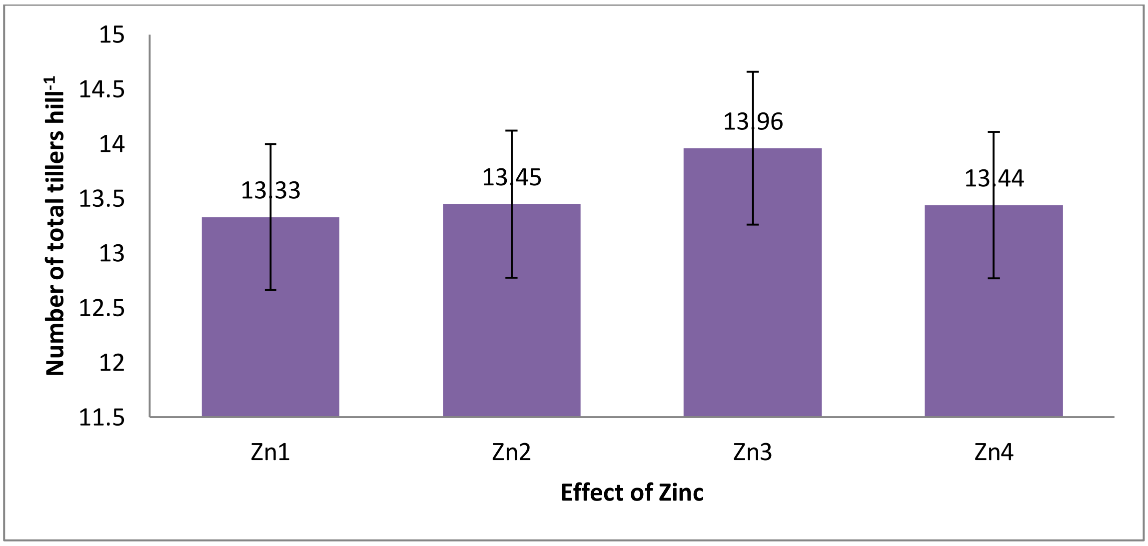


Fig. 9. Effect of Zn on number of total tillers hill^{-1} of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.4.3 Combined effects of Boron and Zinc

Interaction effect of different levels of Boron and Zinc showed significant differences for number of total tillers hill^{-1} of Tia rice (Table 2). The maximum number of total tillers hill^{-1} (17.89) was found from the treatment combination of B_3Zn_3 which was statistically similar with B_1Zn_4 and B_1Zn_3. The minimum number (10.81) was observed from the treatment combination of B_1Zn_1. Correa *et al.* (2006) observed that appropriate Boron availability in soils favors root growth, and a sufficient supply of this micronutrient is very important for adequate rice development.

4.5 Number of panicle m^{-2}

4.5.1 Effect of Boron

The application of different levels of Boron showed significant variation on number of panicle m^{-2} of Tia rice (Fig. 10). The result revealed that the maximum number of panicle (104.53) was obtained from B_3 (10 kg ha^{-1}) where B_4 produced lower panicle number (93.58). It might also be due to increase in length and width of leaves, because Boron is involved in cell division. Khan *et al.* (2007) found spike length was significantly different from control for the same treatment of B application.

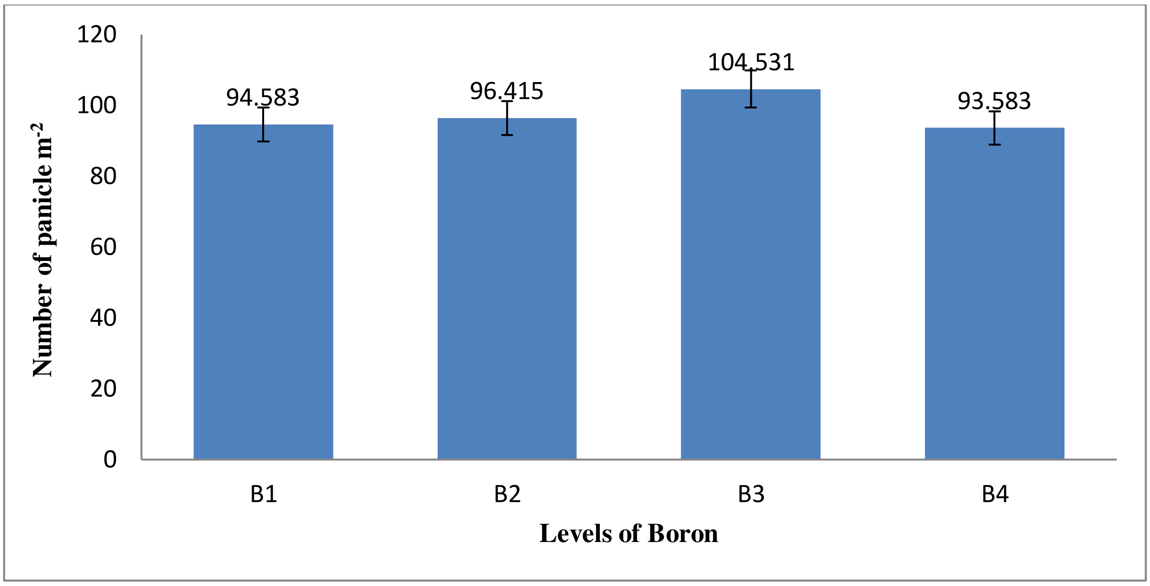


Fig. 10. Effect of Boron on number of panicle m^{-2} of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.5.2 Effect of Zinc

Tia rice showed statistically significant variation in terms of number of panicle m^{-2} by application of different levels of Boron (Fig. 11). Result showed that the highest number of panicle (99.80) was observed in Zn_3 (15 kg ha^{-1}) while the lowest (93.02) was obtained from Zn_1 (Control). It could be attributed to adequate supply of Zinc that might have increased availability and uptake of other nutrients resulting in improvement in metabolic activities. The result obtained from the present study was similar with Babiker (1986). He observed that panicle length was significantly affected by rice cultivars.

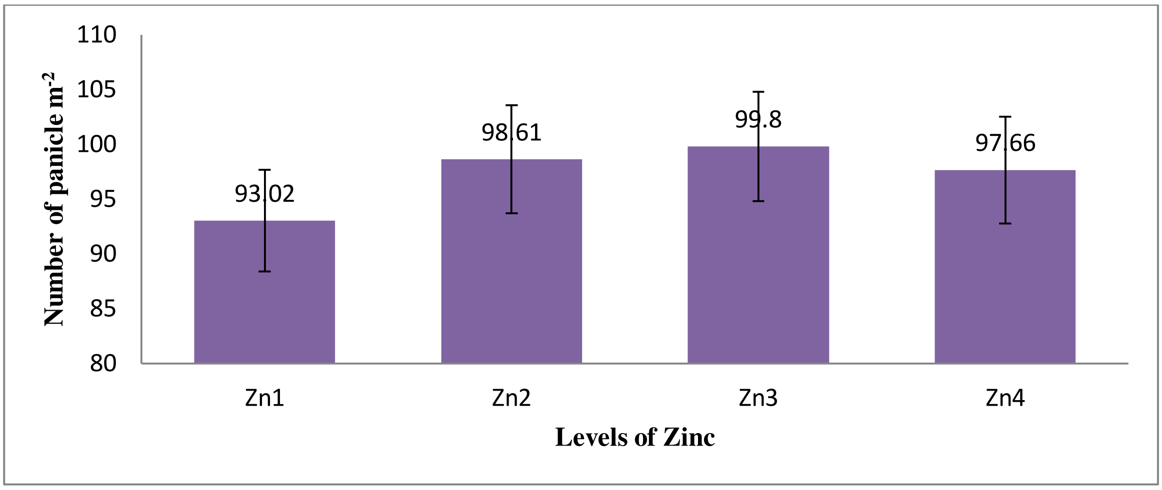


Fig. 11. Effect of Zinc on number of panicle m^{-2} of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.5.3 Combined effects of Zinc and Boron

Combined effect of Boron and Zinc was significant on number of panicle m^{-2} (Table 2). The highest number of panicle m^{-2} (105.3) was recorded from B_3Zn_3 which was statistically similar with B_3Zn_2, B_3Zn_4 and B_1Zn_2. The lowest number of paniclem^{-2} (87.11) was obtained from B_1Zn_1 that showed statistical similarities with B_4Zn_4.

4.6 Panicle length (cm)

4.6.1 Effect of Boron

Panicle length was significant influenced by different levels of Boron in Tia rice (Fig. 12). In this experiment, B_3 (10 kg ha^{-1}) produced the longest panicle (27.14cm) whereas the shortest panicle (25.07 cm) was recorded from B_1 (Control). Khan *et al*. (2007) found spike length was significantly different from control for the same treatment of B application.

The Boron being a component of ferrodoxin and electron transport are also associated with chloroplast. The acceleration in photosynthesis is evident for better vegetative growth (Patil *et al.*, 2008).

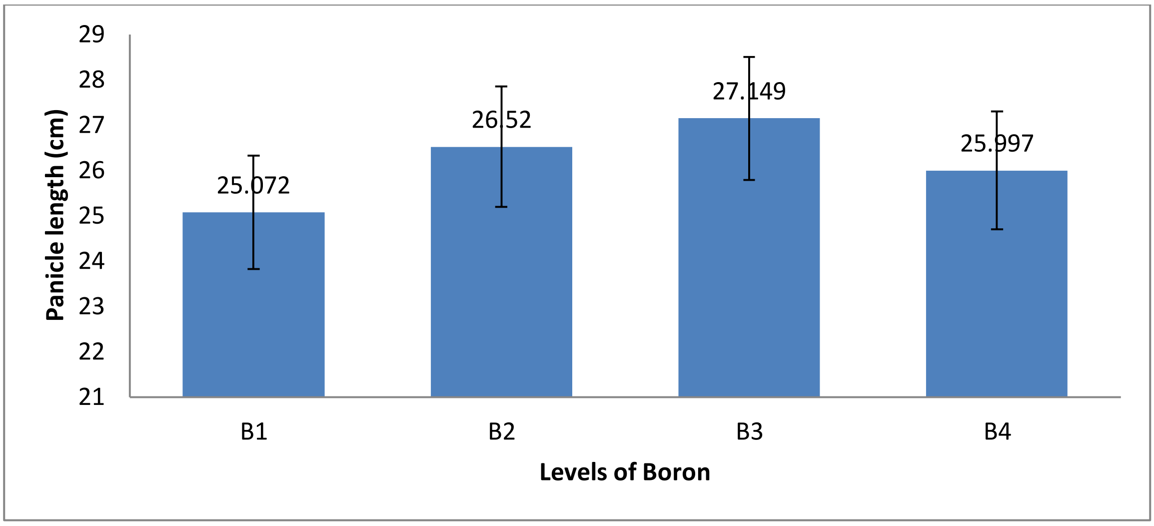


Fig. 12. Effect of Boron on panicle length of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.6.2 Effect of Zinc

The significant variation of *Tia* rice in terms of panicle length was observed by the application of Zinc (Fig. 13). The largest panicle length (26.49 cm) was recorded under Zn_3 (15kg ha^{-1}), while the shortest panicle length (25.66) was recorded under Zn_1 (Control). The result obtained from the present study was similar with Babiker (1986). He observed that panicle length was significantly affected by rice cultivars and $ZnS0_4$ rates.

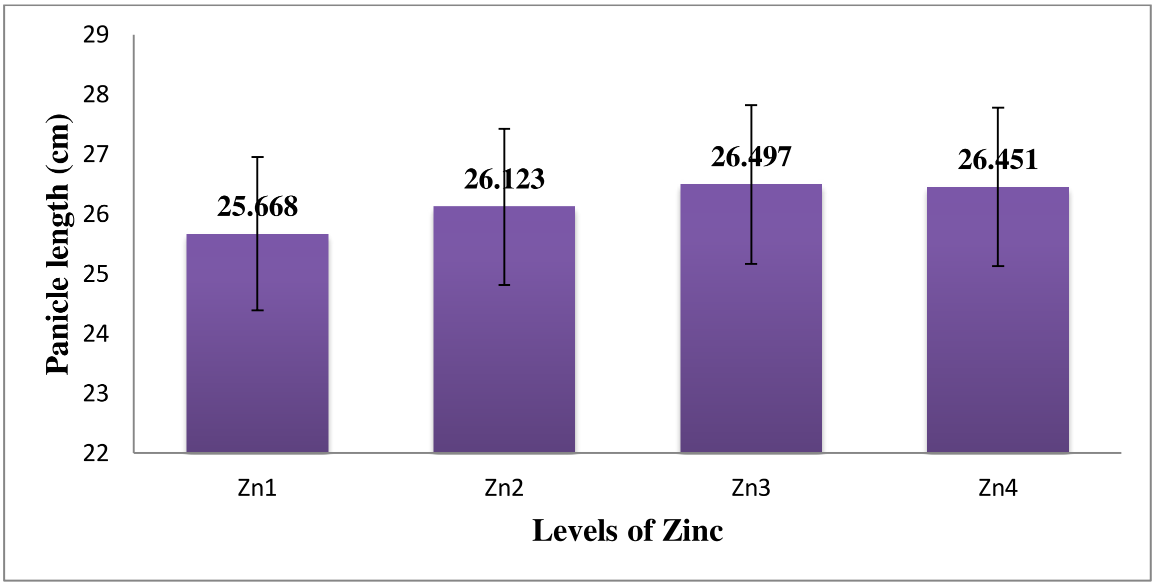


Fig. 13. Effect of Zinc on panicle length of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.6.3 Combined effects of Zinc and Boron

Panicle length of *Tia* rice was significantly influenced by the combined effect of Boron and Zinc (Table 2). The largest panicle length (28.30 cm) was obtained from the treatment combination B_3Zn_3 which was statistically similar with B_3Zn_3 and B_2Zn_1 whereas, the treatment B_1Zn_1 produced the shortest panicle (22.83 cm). Increase in panicle length by the application of Zn and B mixture might be due to higher CGR. Qadir *et al.* (2013) reported that the combined application of micronutrients (Iron, Zinc, Manganese and Boron) enhanced the yield of rice

Table 2. Effect of Boron and Zinc on the number of total tillers hill^{-1}, number of panicle m^{-2} and panicle length (cm) of *Tia* rice.

Treatments	Number of total tillers hill^{-1}	Number of panicle m^{-2}	Panicle length (cm)
B_1Zn_1	10.81 fg	87.11 e	22.83 f
B_1Zn_2	14.42 b	103.2 ab	26.12 de
B_1Zn_3	17.18 a	93.00 d	25.29 e
B_1Zn_4	16.14 a	95.00 d	26.05 de
B_2Zn_1	14.61 b	89.00 e	25.31 e
B_2Zn_2	11.24 f	93.66 d	28.27 a
B_2Zn_3	14.31 b	100.0 c	26.22 de
B_2Zn_4	14.24 b	103.0 abc	25.27 e
B_3Zn_1	17.37 a	103.0 abc	25.15 e
B_3Zn_2	12.15 ef	104.7 a	27.09 bcd
B_3Zn_3	17.89 a	105.3 a	28.30 ab
B_3Zn_4	11.64 ef	105.1 a	28.05 abc
B_4Zn_1	13.66 bc	93.00 d	26.09 de
B_4Zn_2	12.34 def	92.89 d	25.28 e
B_4Zn_3	12.58 cde	101.1bc	26.27 de
B_4Zn_4	14.30 b	87.33 e	26.34 cde
LSD	1.245	3.111	1.736
Level of significance	**	**	*
CV (%)	11.91	4.24	8.80

4.7 Grain weight at different DAT

4.7.1 Effect of Boron

Different levels of Boron showed significant differences on grain weight *Tia* rice at 50, 60 and 70 days after transplanting (DAT) (Fig. 14). At 50, 60 and 70 DAT, the highest grain growth rate (0.019, 0.026 and 0.033 g) was observed from B_3 and the lowest grain growth rate (0.13, 0.021,029 g) was recorded from B_1 (0 kg B ha^{-1}) at same DAT.

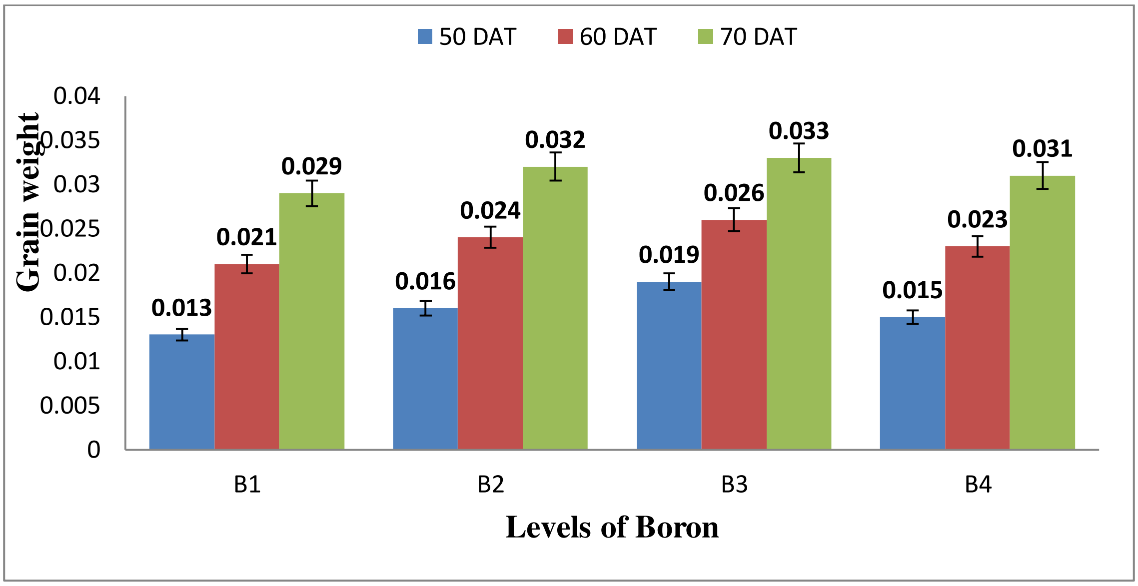


Fig. 14. Effect of Boron on grain weight of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.7.2 Effect of Zinc

Grain weight of *Tia* rice varied significantly at 50, 60 and 70 DAT due to the different levels of Zinc (Fig. 15). At 50, 60 and 70 DAT the highest grain growth rate (0.02, 0.025 and 0.031 g) was recorded from Zn_3 (15 kg ha^{-1}), while the lowest (0.013, 0.021 and 0.029 g) was observed from Zn_1 (0 kg ha^{-1}) at same DAT.

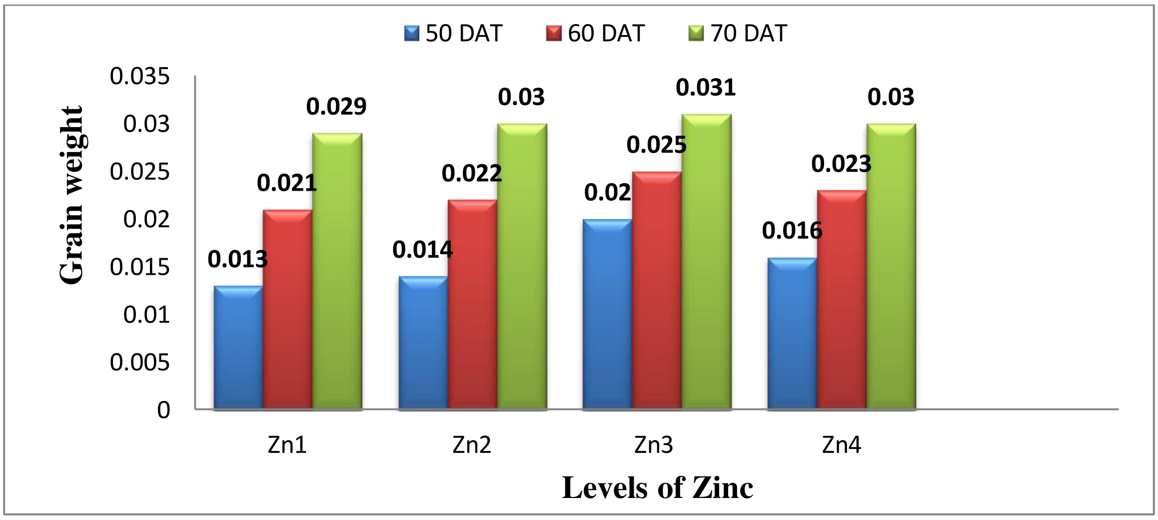


Fig. 15. Effect of Zinc on grain growth rate of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.7.3 Combined effects of Zinc and Boron

Interaction effect of different levels of Boron and Zinc showed significant differences for grain weight of *Tia* rice at 50, 60 and 70 DAT under the present trial (Table 3). At 50, 60 and 70 DAT, the highest grain weight (0.029, 0.032 and0.0390 g) was found from the treatment combination of B_3Zn_3 (10 kg B ha^{-1} and 15 kg Zn ha^{-1}), whereas the lowest grain growth rate (0.011, 0.019 and0.0130g) was observed from the treatment combination of B_1Zn_1 (0 kg B ha^{-1} and 0 kg Zn ha^{-1}) at same DAT. This might be due to the auxin metabolism and increased photosynthetic rate by interaction of residual amount of Zinc and Boron in soil.

Table 2. Effect of Boron and Zinc on grain growth rate (g) of *Tia* rice

Treatments	**Grain growth rate**		
	50 DAT	60 DAT	70 DAT
B_1Zn_1	0.0 11f	0.019 f	0.0130 i
B_1Zn_2	0.013de	0.020ef	0.0290 g
B_1Zn_3	0.012ef	0.024 c	0.0310 e
B_1Zn_4	0.014d	0.021def	0.0310 e
B_2Zn_1	0.013de	0.023cd	0.0330 c
B_2Zn_2	0.0 13de	0.020ef	0.0340 b
B_2Zn_3	0.014d	0.020ef	0.0310 e
B_2Zn_4	0.012ef	0.022cde	0.0286 g
B_3Zn_1	0.0 12ef	0.021def	0.0290 g
B_3Zn_2	0.0 18b	0.028b	0.0320 d
B_3Zn_3	0.029a	0.032a	0.0390 a
B_3Zn_4	0.019b	0.026b	0.0330 c
B_4Zn_1	0.016c	0.024c	0.0270 h
B_4Zn_2	0.014d	0.023 cd	0.0300 f
B_4Zn_3	0.014d	0.024c	0.0310 e
B_4Zn_4	0.014d	0.021def	0.0300 f
LSD	0.0019	0.002	0.00070
Level of significance	**	**	**
CV (%)	16.56	11.69	3.11

4.8 Number of filled grains panicle^{-1}

4.8.1 Effect of Boron

Number of filled grains panicle^{-1} of *Tia* rice was significantly differed on different levels of Boron (Fig. 16). The maximum number of filled grains panicle^{-1} (157.43) was obtained from B_3, whereas the minimum number (129.10) was found from B_1. This may be due to provision of Boron in *Tia* all stages which might have enhanced the accumulation of assimilate in the grains and thus resulting in heavier grains (Arif *et al*., 2006). These results were closely related with the findings of Tahir *et al*. (2008).

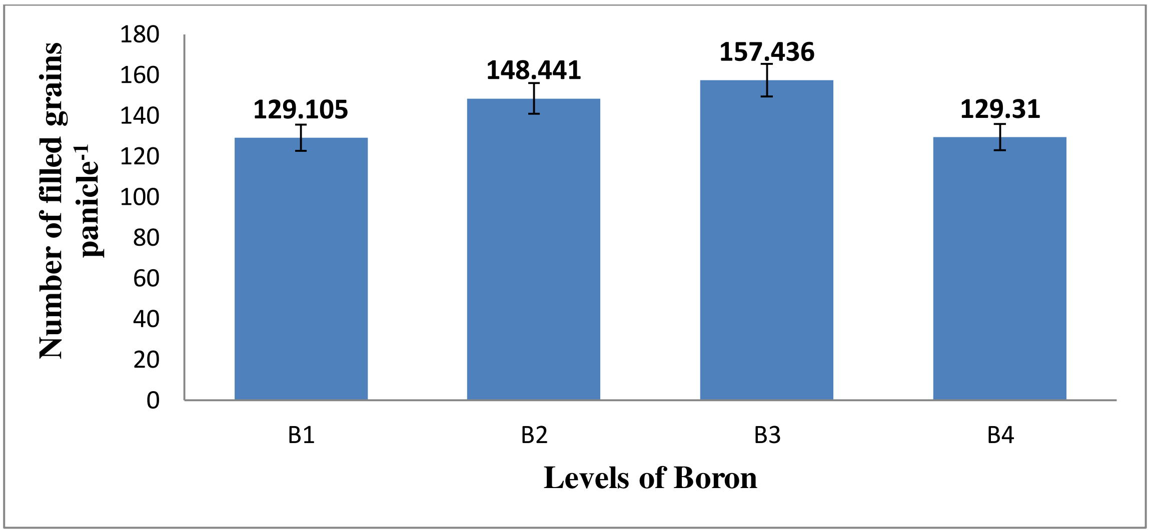


Fig. 16. Effect of Boron on number of filled grain panicle^{-1} of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.8.2 Effect of Zinc

The number of filled grains panicle^{-1} of *Tia* rice was varied significantly due to the application of different levels of Zinc (Fig. 17). The maximum number of filled grains panicle^{-1} (154.198) was observed from Zn_4, while the minimum number (127.23) was recorded from Zn_1 (Fig. 17). The result obtained from the present study was similar with Babiker (1986). He observed that panicle length was significantly affected by rice cultivars and $ZnSO_4$ rates. Sharma (2006) found that Zinc levels may cause male ster ility and induce floral abnormalities.

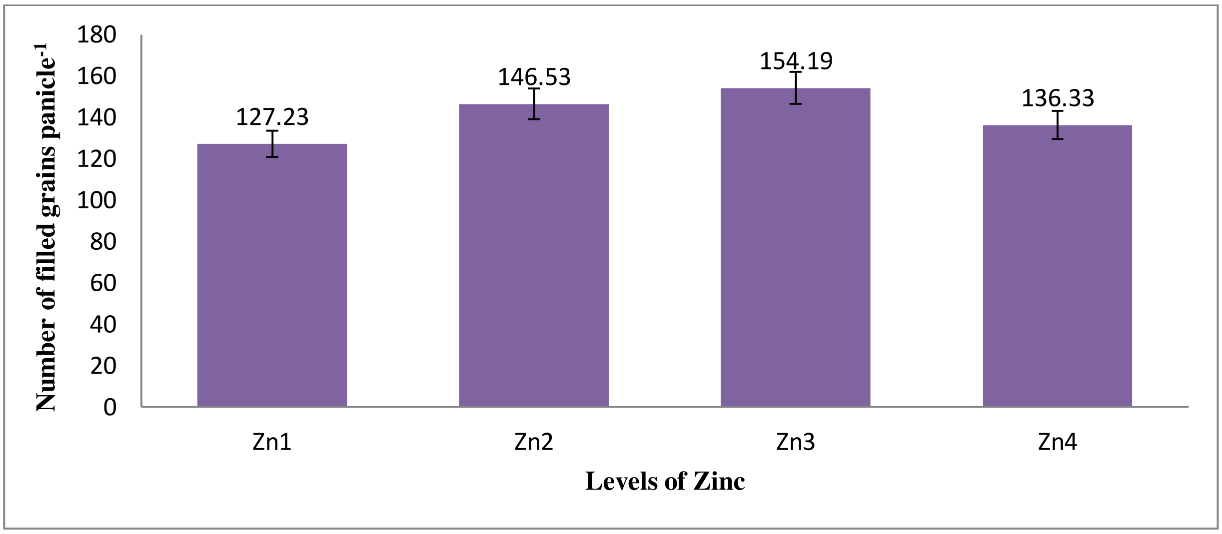


Fig. 17. Effect of Zinc on number of filled grains of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.8.3 Combined effect of Boron and Zinc

Interaction effect of different levels of Boron and Zinc had significant differences for number of filled grains panicle^{-1} of Tia rice (Table 4). The maximum number of filled grains panicle^{-1} (186.1) was obtained from the treatment combination of B_3Zn_3, whereas the treatment combination of B_1Zn_1 produced the minimum number (111.2). Dobberman and Fairhurst (2000) reported that Boron and Zinc levels increased the yield of rice through enhancing the grain filling.

4.9 Number of unfilled grains panicle^{-1}

4.9.1 Effect of Boron

Different levels of Boron showed statistically significant differences in terms of number of unfilled grains panicle^{-1} (Fig. 18). The result revealed that the maximum number of unfilled grains panicle^{-1} (23.68) was observed from B_1 (0 kg ha^{-1}), the minimum number (19.93) was observed from B_3 (10 kg ha^{-1}).

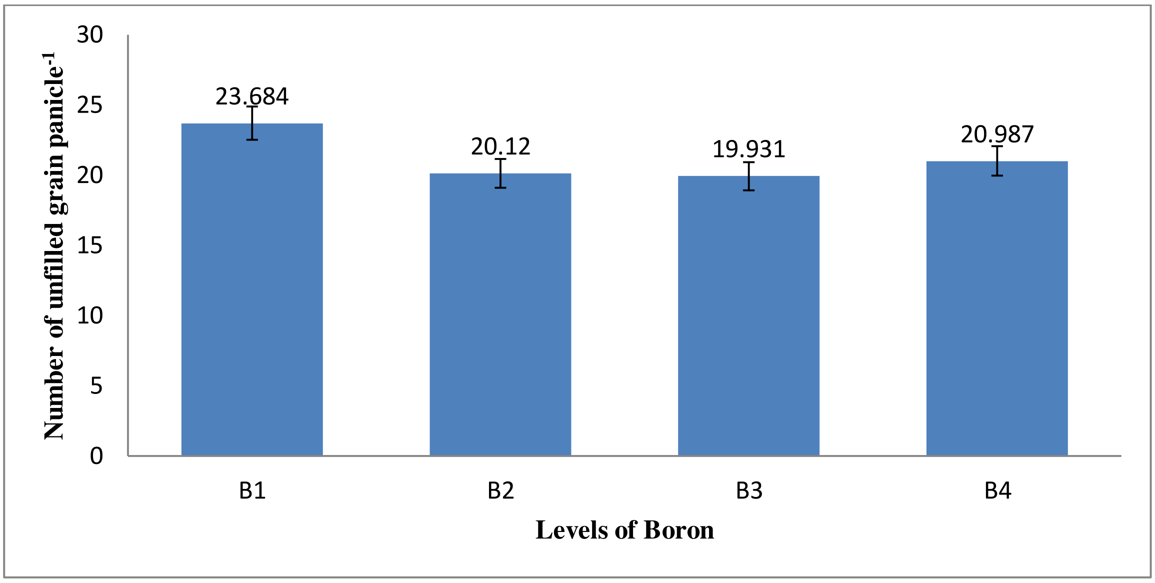


Fig. 18. Effect of Boron on number of unfilled grain panicle^{-1} of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4= 15 kg B ha^{-1})

4.9.2 Effect of Zinc

Number of unfilled grains panicle^{-1} was varied significantly due to the application of different levels of Zinc (Fig. 19). Zn_1 (0 kg Zn ha^{-1}) produced the highest number of unfilled grains panicle^{-1} (25.62), while the minimum number (17.98) was obtained from Zn_3 i.e. 15 kg Zn ha^{-1}. This result reconfirms the findings of Siddika (2013).

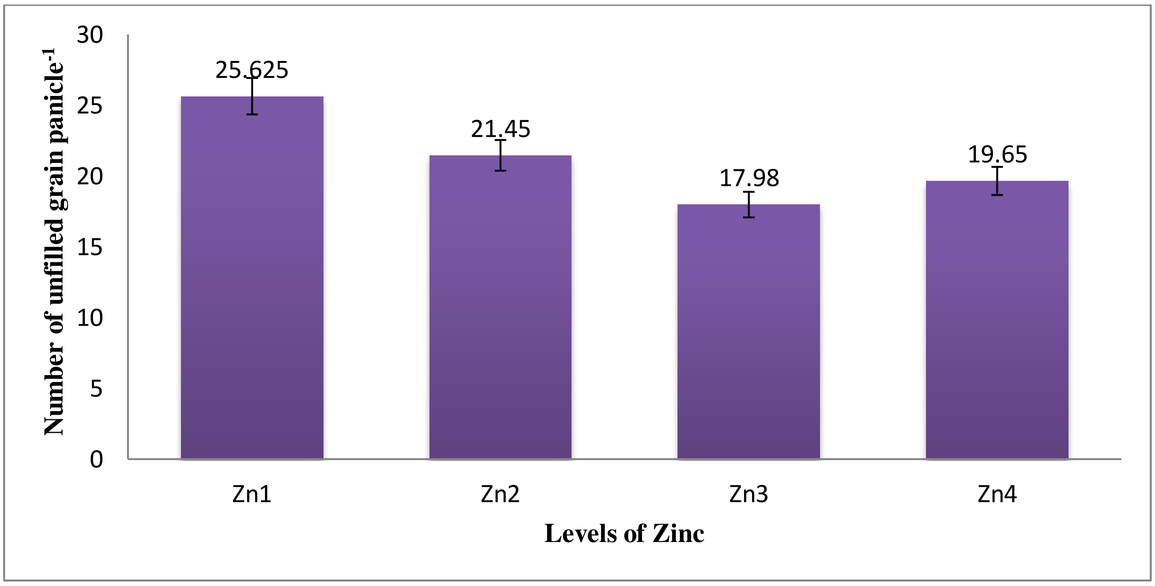


Fig. 19. Effect of Zinc on number of unfilled grains of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.9.3 Combined effects of Boron and Zinc

Statistically significant variation was recorded due to the interaction effect of different levels of Boron and Zinc on number of unfilled grains panicle^{-1} (Table 4). The maximum number of unfilled grains panicle^{-1} (31.00) was observed from B_1Zn_1 (0kg B ha^{-1} and 0 kg Zn ha^{-1}), whereas the minimum number (16.31) was found from B_3Zn_3 (10 kg ha^{-1} and 15 kg Zn ha^{-1}) treatment combination which was statistically similar with B_2Zn_2.

4.10 Number of total grains panicle^{-1}

4.10.1 Effect of Boron

Statistically significant variation was observed in terms of number of total grains panicle^{-1} due to different levels of Boron (Fig. 20). Data revealed that the maximum number of total grains panicle^{-1} (177.86) was obtained from B_3 (10 kg ha^{-1}), while the minimum number (149.22) was in B_1 (5 kg ha^{-1}).

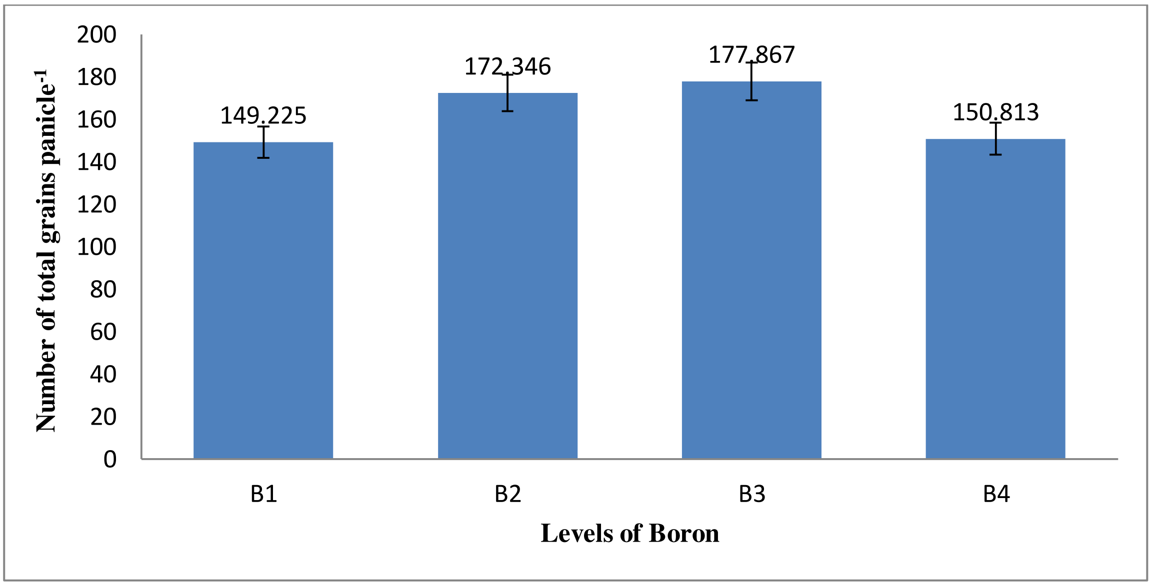
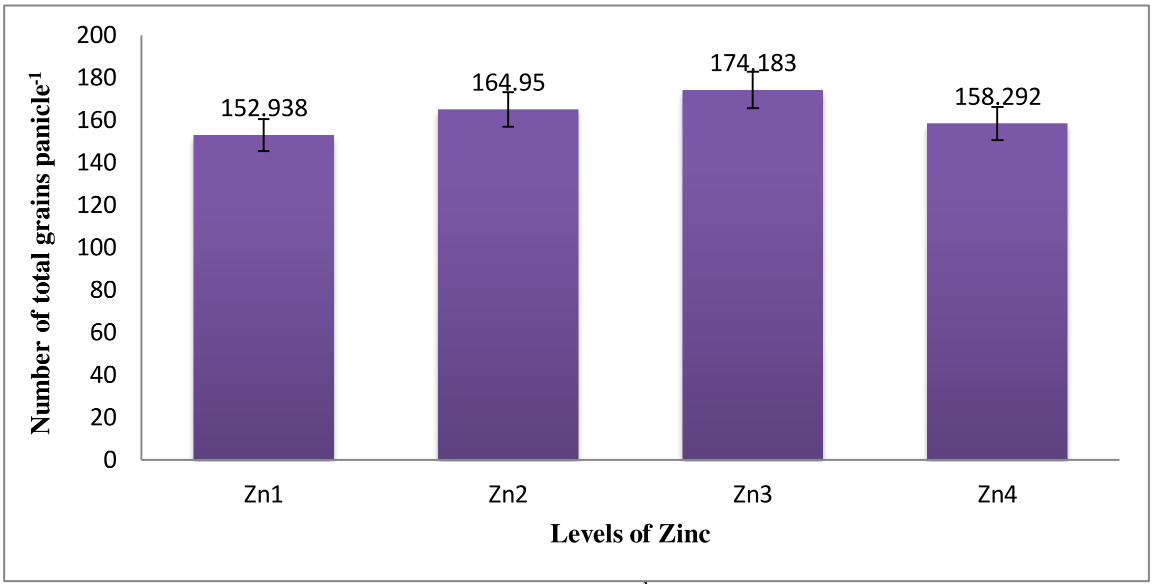


Fig. 20. Effect of Boron on number of total grains panicle-1 of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.10.2 Effect of Zinc

Number of total grains panicle^{-1} showed statistically significant variations due to the application different levels of Zinc (Fig. 21). The maximum number of total grains panicle^{-1} (174.18) was produced by Zn_3 (15 kg Zn ha^{-1}), whereas the minimum number



(152.93) was attained from Zn_1 i.e. 0 kg Zn ha^{-1}. Hossain *et al.* (2001) found that the application of Zinc greatly increased the total grains per panicle.

Fig. 21. Effect of Zinc on number of total grains of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

4.10.3 Combined effect of Zinc and Boron

Significant variation was observed in total grains $panicle^{-1}$of *Tia* rice by combined effect of Zinc and Boron (Table 4). The highest total grains $panicle^{-1}$ (203.1) was attained from B_3Zn_3 (10 kg B ha^{-1} and 15 kg Zn ha^{-1}), whereas the minimum number (142.0) was found in B_1Zn_1 treatment combination.

Table 4. Effect of Boron and Zinc on the number of filled grains panicle^{-1}, unfilled grains panicle^{-1} and total grains panicle^{-1} of *Tia* rice

Treatments	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}	Number of total grains panicle^{-1}
B_1Zn_1	111.2 j	31.00 a	142.0 k
B_1Zn_2	159.3 d	21.31 e	181.3 d
B_1Zn_3	134.1 g	29.09 b	163.2 f
B_1Zn_4	128.2 h	22.11 de	151.0 i
B_2Zn_1	134.2 g	23.06 d	157.3 h
B_2Zn_2	133.2 gh	20.11e	146.3 j
B_2Zn_3	129.2 gh	18.11 fg	147.3 j
B_2Zn_4	119.9 i	26.20 c	146.1 j
B_3Zn_1	122.1 i	21.21 e	153.1 i
B_3Zn_2	141.2 f	18.32 fg	160.2 g
B_3Zn_3	186.1 a	16.31 h	203.1 a
B_3Zn_4	180.3 b	19.27 f	199.1 b
B_4Zn_1	173.50 c	25.22 c	198.0 b
B_4Zn_2	152.4 e	19.20 f	172.0 e
B_4Zn_3	173.2 c	17.31 gh	191.2 c
B_4Zn_4	172.1 c	22.22 de	194.3 b
LSD	5.569	1.739	2.453
Level of significance	**	**	**
CV (%)	5.24	10.89	2.00

4.11 Weight of 1000-grain

4.11.1 Effect of Boron

The 1000-grain weight of *Tia* rice was varied significantly for different levels of Boron (Fig. 22). The highest 1000-grain weight (21.38 g) was attained in B_3 (10.0 kg B ha^{-1}), while the lowest weight (18.19 g) was found in B_1 (0 kg B ha^{-1}). As presence of B in plant regulates the translocation of assimilates to grains (Arif *et al.*, 2006), this might have resulted in increased 1000-grain weight. Xiong (1987) concluded that the application of 0.8-1.2 ppm B resulted in 1-5 days earlier heading and the 1000-grain weight increased with B application. Khan *et al*. (2007) also observed that 1000-grain weight was significantly different with B treatments.

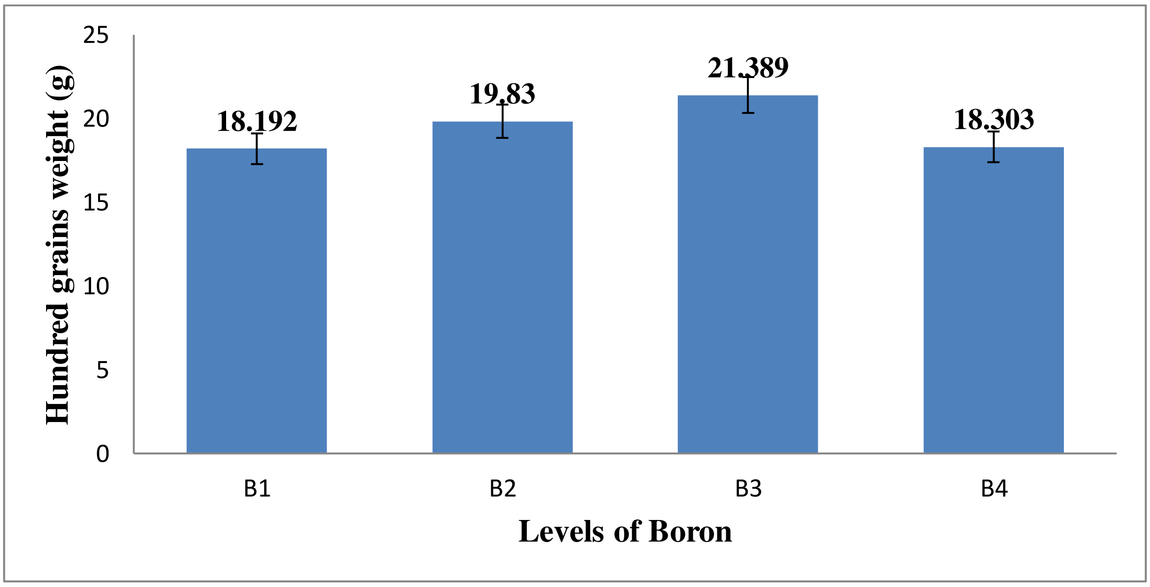


Fig. 22. Effect of Boron on weight of 1000-grain of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.11.2 Effect of Zinc

Statistically significant variation for weight of 1000-grains was observed in Tia rice due to

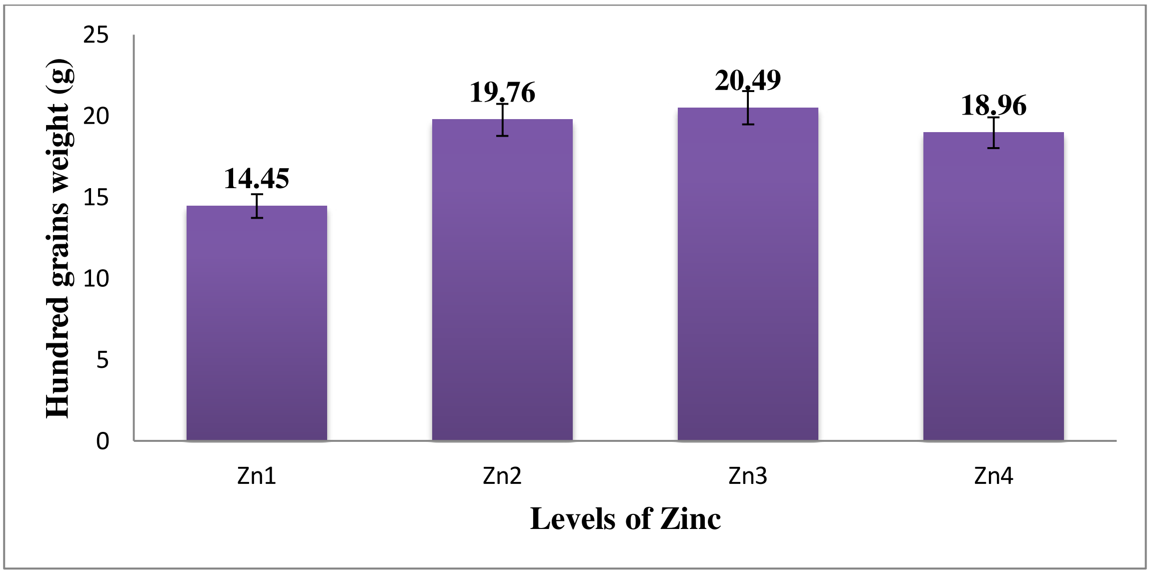


Fig. 23. Effect of Zinc on weight of 1000-grain of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

different levels of Zinc (Fig. 23). The highest weight of 1000-grains (20.49 g) was recorded from Zn_3 (15 kg Zn ha^{-1}) and the lowest weight (14.45 g) at Zn_1 (0 kg Zn ha^{-1}). Ullah *et al*. (2001) found the highest 1000-grain weight (28.700 g), from 20 kg Zinc sulfate ha^{-1}. Cheema *et al*. (2006) reported that 1000-grain weight showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Babiker (1986) observed that 1000-grain weight was significantly affected by rice cultivars and $ZnSO_4$ rates.

4.11.3 Interaction effect of Zinc and Boron

Interaction effect of Boron and Zinc showed significant variation on 1000-grain weight of Tia rice (Table 5). The highest weight of 1000 grain (22.59 g) was obtained from B_3Zn_4 (10 kg B ha^{-1} and 20 kg Zn ha^{-1}) which was statistically similar with B_3Zn_3, whereas the lowest weight (15.29g) was recorded in B_4Zn_4 (15 kg B ha^{-1} and 20 kg Zn ha^{-1}) treatment combination. It might be due to more efficient participation of Boron and Zinc in various metabolic processes which enhanced accumulation of assimilates in the grains and resulted in heavier grain. Soleimani (2006) who recorded significantly increased seeds weight by integrating micronutrients like Zn and B and others micronutrients.

4.12 Grain yield (tha^{-1})

4.12.1 Effect of Boron

Due to the different levels of Boron grain yield was influenced significantly under the

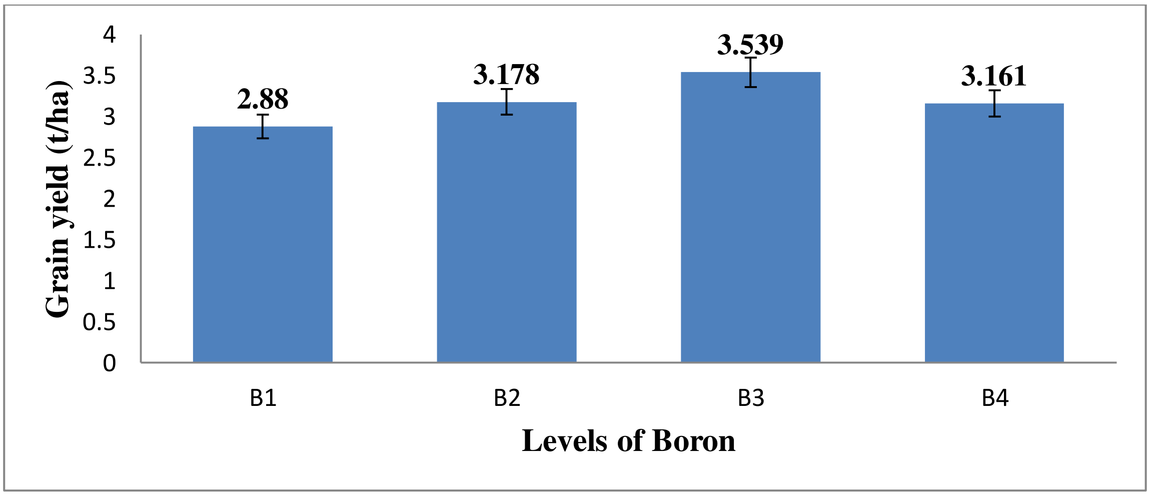


Fig. 24. Effect of Boron on grain yield of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

present trial (Fig. 24). The highest grain yield (3.53 t ha^{-1}) was observed from B_3 (10 kg B ha^{-1}), while the lowest grain yield (2.88 t ha^{-1}) was found in B_1 (0 kg Zn ha^{-1}). Boron helps in flowering and grain formation in rice. Yield increase with B occurred because of reduced panicle sterility and increased productive tillers hill^{-1} (Riaz and Irshad, 2011). Mandal *et al*. (1987) found that an application of 16 kg borax ha^{-1} along with NPK increased the yield components and gave higher paddy yields. Singh *et al.* (1990) observed that increase in yield due to B application was 31% higher in submerged condition than in rain fed conditions. The highest grain yield of 3.66 t ha^{-1} and was attained from the application of B under submerged condition.

4.12.2 Effect of Zinc

Different levels of Zinc showed statistically significant variation for grain yield of Tia rice (Fig. 25). The highest grain yield (3.36 t ha^{-1}) was found in Zn_4 (20 kg Zn ha^{-1}), whereas the lowest grain yield (2.95 t ha^{-1}) was observed from control (0 kg Zn ha^{-1}). Zinc is basically involves in several biochemical processes including carbohydrate metabolism, sugar transport, lignifications. Zinc deficiency is field. Swamp (1983) stated that the grain yields of rice were increased with application of Zn.

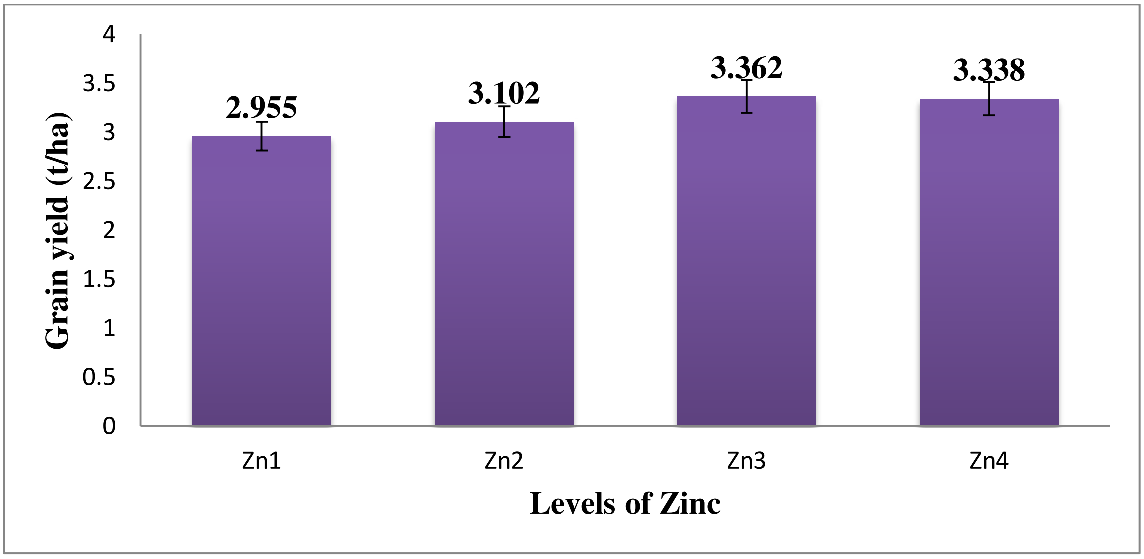


Fig. 25. Effect of Zinc on grain yield of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

The most widespread micronutrient disorder in lowland rice and application of Zinc along with NPK fertilizer increases the grain yield dramatically in most cases (Chaudhary *et al*., 2007; Muthukumararaja and Sriramachandrasekharan, 2012). Khan *et al.* (2007) reported that increasing levels of Zn significantly influenced grain yield of rice. Ullah *et al.* (2001) found that soil application of Zinc sulphate increased grain yields. Cheema *et al.* (2006) reported that paddy yield showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Cihatak *et al.* (2005) found that that Zinc fertilizer application significantly increased grain yields, uptake of Zn by plant. Babiker (1986) observed that 50 kg $ZnSO_4$ ha^{-1}, especially for nursery grown rice, was the most effective and economic rate for improving grain yield and its components. Jahiruddin *et al.* (1981) reported that when Zn was applied to acid clay type soil of Bangladesh, a significant increase in the grain and straw yield of boro rice was obtained. Sharma *et al.* (1982) observed that the grain yield of rice was increased from 3.21 t ha^{-1} without Zn to 5.78 t ha^{-1} with Zn application. Ahmed *et al.* (1983) reported increase in all growth parameters of rice after Zn application in the experimental plot.

4.12.3 Combined effect of Zinc and Boron

Grain yield of *Tia* rice was increased significantly due to interaction effect between Boron and Zinc (Table 5). The highest grain yield (4.93 tha^{-1}) was recorded from B_3Zn_3 (10 kg B ha^{-1} and 15 kg Zn ha^{-1}) and the lowest (2.26 tha^{-1}) was from B_1Zn_1. The application of Zn and B improved dry matter and grain yield due to improvement in allometric traits, chlorophyll and relative water contents, and increase in yield components.

This might be due to increased, starch, protein nitrogen, soluble protein and specific activity of carbonic anhydrase, specific activities of acid phosphatase and ribonuclease in leaves and pods by residues of Zinc and Boron, and the interaction of residues of Zinc and Boron with applied RDF (NPK) This was further supported by Chatterjee (2008).

Increase in grain yield and yield attributes due to increase in doses of Zinc and different methods of application of Boron might be due to the reason that Zinc is actively involved in the physiological process in plants (Singh *et al.*, 2015).

4.13 Straw yield (ton ha^{-1})

4.13.1 Effect of Boron

Statistically significant variation was recorded in terms of straw yield ha^{-1} due to different levels of Boron (Fig. 26). The highest straw yield (9.96 t ha^{-1}) was observed from B_2 (5 kg B ha^{-1}), while the lowest straw yield (8.81 t ha^{-1}) was observed from B_1 (0 kg B ha^{-1}). The significant improvement in yield and fruiting efficiency with B application. Ullah *et al.*, (2001) found that soil application of Boron increased straw yields.

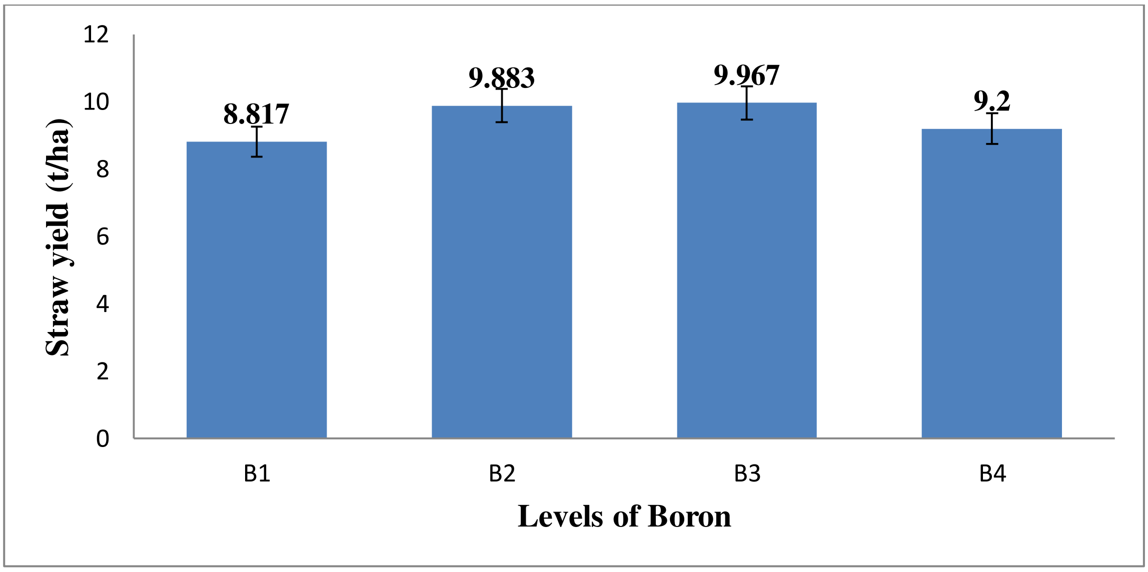


Fig. 26. Effect of Boron on straw yield of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.13.2 Effect of Zinc

Straw yield ha^{-1} showed statistically significant variation due to different levels of Zinc (Fig.

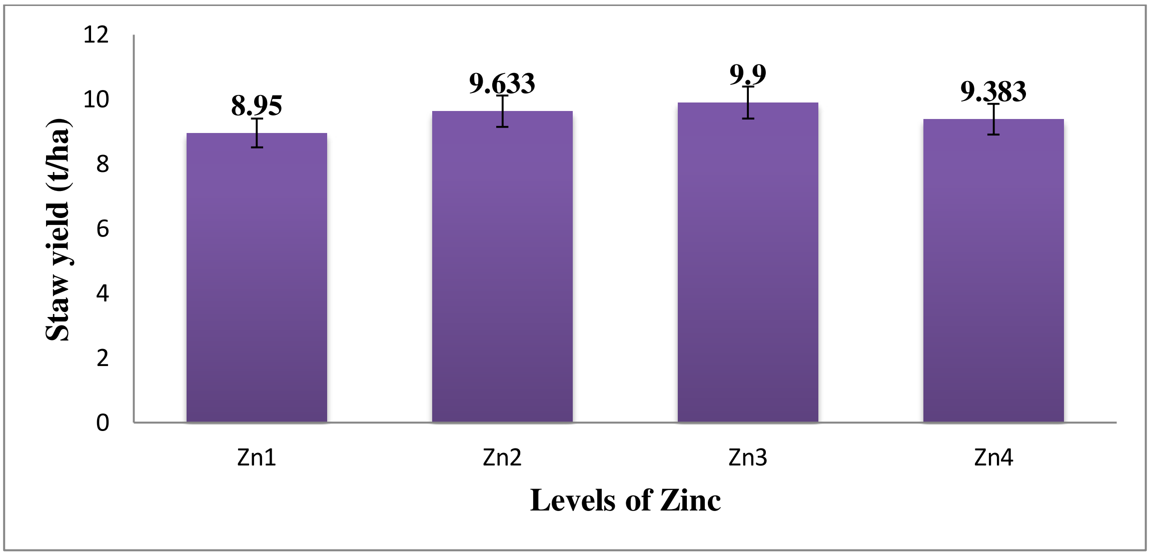


Fig. 27. Effect of Zn on straw yield of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

27). The highest straw yield (9.9 t ha^{-1}) was recorded from Zn_3 (15 kg Zn ha^{-1}), whereas the lowest straw yield (8.95 t ha^{-1}) was obtained from Zn_1 i.e. 0 kg Zn ha^{-1}. Khan *et al.* (2007) reported that the increasing levels of Zinc significantly influenced grain yield of rice. Cheema *et al.* (2006) reported that straw yield showed positive correlation with increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. The increases in rice straw yield by Zn application were relatively high, indicating the necessity of Zn application to plants. Cihatak *et al.* (2005) found that that Zinc fertilizer application significantly increased straw yield and uptake of Zinc by plant.

4.13.3 Interaction effect of Zinc and Boron

Due to the interaction effect between Boron and Zinc straw yield ha^{-1} of *Tia* rice increased significantly (Table 5). The highest straw yield (11.80 t ha^{-1}) was observed from B_3Zn_3 (10 kg B ha^{-1} and 15 kg Zn ha^{-1}) which was statistically similar with B_2Zn_2, while the lowest straw yield (6.667 t ha^{-1}) was found from B_1Zn_1 (0 kg B ha^{-1} and 0 kg Zn ha^{-1}) treatment combination. It might be due to activation of different physiological processes like stomatal regulation, chlorophyll formation, enzyme activation and biochemical processes through application of Boron and Zinc.

Table 5. Effect of Boron and Zinc on 1000-grain weight (g), grain yield (t/ha), straw yield (ton/ha) and harvest index (%) of *Tia* rice

Treatments	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
B_1Zn_1	15.29 i	2.26k	6.66 i	25.33 de
B_1Zn_2	19.43def	2.57k	9.27 defgh	21.62kl
B_1Zn_3	19.86 cdef	3.45bcd	9.53 cdefg	25.69 de
B_1Zn_4	19.17 def	2.31k	9.80cdef	25.52de
B_2Zn_1	19.91 cde	3.26cdefg	9.20defgh	23.80fgh
B_2Zn_2	16.95 h	3.44bcde	11.53 ab	21.19 klmn
B_2Zn_3	18.74ef	3.02fgh	8.53gh	25.00 def
B_2Zn_4	17.17 gh	2.98ghij	10.60 bc	21.39 klm
B_3Zn_1	20.84 bc	3.17efhi	8.53gh	19.99n
B_3Zn_2	20.41 bcd	3.35bcef	9.00efgh	26.95 c
B_3Zn_3	22.59 a	4.93a	11.80 a	35.69 a
B_3Zn_4	21.72ab	3.61b	10.20 cd	32.58 b
B_4Zn_1	20.34 bcd	3.11fg	8.26 h	27.09 c
B_4Zn_2	19.08 def	3.22cdefgh	8.73 fgh	26.13cd
B_4Zn_3	20.87 bc	3.26 cdefg	9.73 cdef	25.53d
B_4Zn_4	18.51 fg	3.04fgh	10.07 cde	23.94 fg
LSD	1.401	0.322	1.114	1.21
Level of significance	**	*	*	**
CV (%)	9.57	7.85	15.61	9.09

4.14 Harvest index (%)

4.14.1 Effect of Boron

Different levels of Boron showed statistically significant differences in terms of harvest index of Tia rice (Fig. 28). The highest harvest index (25.30%) was recorded from B_3 (10.0 kg ha^{-1}), while the lowest harvest index (22.84%) was found from B_1 (0 kg ha^{-1}). Improvement in harvest index resulted from B application might be due to better starch utilization that results in higher seed setting and translocation of assimilates to developing grains, which increases the grain size and number of grains per panicle (Hussain *et al*., 2012).

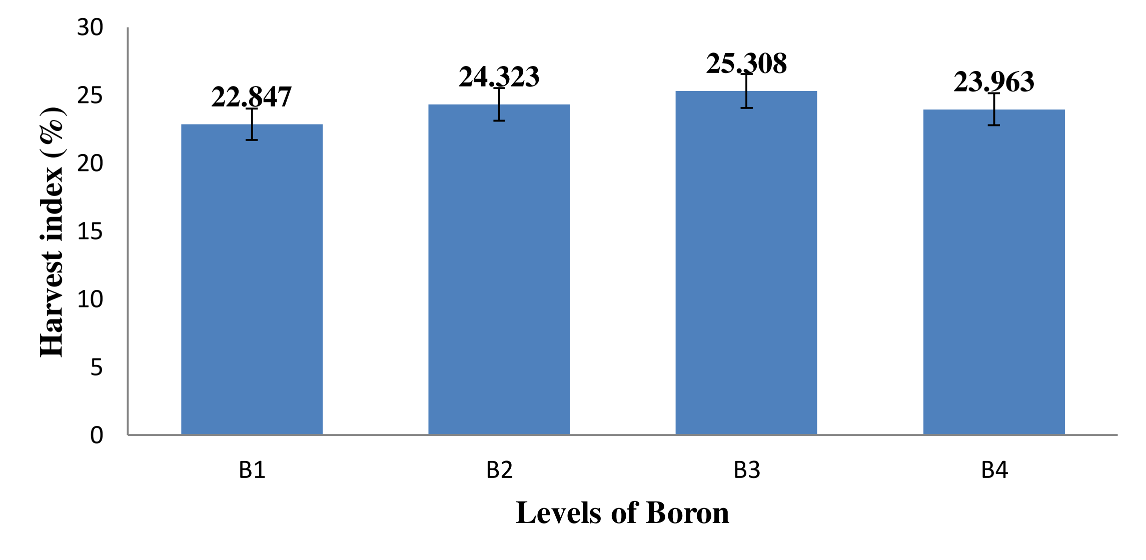


Fig. 28. Effect of Boron on harvest index of *Tia* rice (B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1})

4.14.2 Effect of Zinc

Harvest index showed statistically significant variation due to different levels of Zinc (Fig. 29). The highest harvest index (25.85%) was recorded from Zn_3 (15 kg Zn ha^{-1}) and the

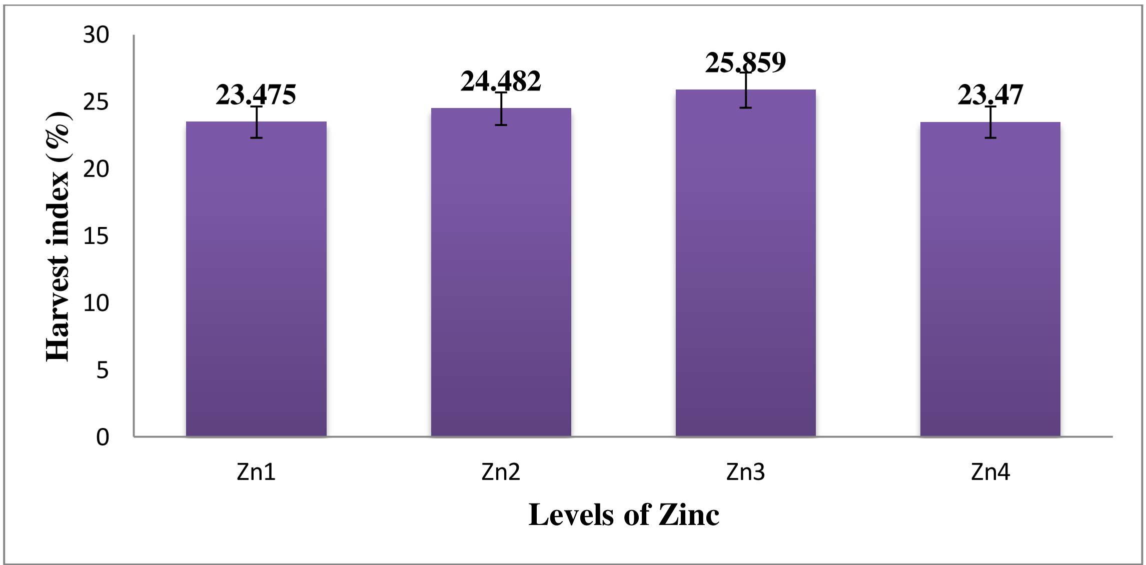


Fig. 29. Effect of Zinc on harvest index of *Tia* rice (Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1}, Zn_3 = 15 kg Zn ha^{-1}, Zn_4 = 20 kg Zn ha^{-1})

lowest harvest index (23.47%) was obtained from Zn_1 i.e. 0 kg Zn ha^{-1}. Cheema *et al.* (2006) reported that harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Babiker (1986) reported that harvest index was significantly affected by rice cultivars and $ZnSO_4$ rates.

4.14.3 Interaction effect of Zinc and Boron

Statistically significant variation was recorded due to interaction effect interaction (Boron × Zinc) on harvest index of *Tia* rice (Table 5). The highest harvest index (35.69%) was observed from B_3Zn_3 (10 kg B ha^{-1} and 15 kg Zn ha^{-1}), whereas the lowest harvest index (21.19%) was found from B_3Zn_1.

CHAPTER V

SUMMARY AND CONCLUSION

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The experiment was conducted at Research Field of Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh during January, 2017 to April, 2017. The design of the experiment was randomized complete block design (RCBD) with three replications. The experiment was two factorial viz. factor A: B_1 = 0 kg B ha^{-1}, B_2 = 5 kg B ha^{-1}, B_3 = 10 kg B ha^{-1} and B_4 = 15 kg B ha^{-1} and Factor B: Zn_1 = 0 kg Zn ha^{-1}, Zn_2 = 10 kg Zn ha^{-1} and Zn_3 = 15 kg Zn ha^{-1} Zn_1 = 20 kg Zn ha^{-1}. Data were recorded on different growth, and yield contributing parameters.

In case of different levels of Boron application, significant variation was attained for all parameters of *Tia* rice. Results revealed that the highest plant height (89.07 cm), effective tiller $hill^{-1}$ (9.89) and the highest total grain $panicle^{-1}$ (177.87) was found in B_3 (10 kg B ha^{-1}). Again, the longest panicle (27.14 cm), number of panicle (104.33), highest filled grain $panicle^{-1}$ (157.43), 1000-seed weight (21.38 g), grain yield (3..53 t ha^{-1}), the highest grain weight (0.019, 0.026 and 0.033) was attained in B_3 (10 kg B ha^{-1}) at 50, 60 and 70 DAT, respectively and the highest un-filled grain $panicle^{-1}$ (23.68) and non-effective tiller $hill^{-1}$ (7.22) was found in B_1 (Control). On the other hand, the shortest (84.86 cm), panicle length (25.07 cm), filled grain $panicle^{-1}$ (129.10), 1000-seed weight (14.09 g), grain yield (2.88 t ha^{-1}), straw weight (8.81 t ha^{-1}) was recorded from B_1 (Control).

In terms of different levels of Zn application to *Tia* rice, significant variation was recorded. Results indicated that the tallest plant (88.99 cm), highest number of total tiller $hill^{-1}$ (14.80), number of effective tiller $hill^{-1}$ (8.85), the highest grain weight (0.02, 0.025 and 0.031 g) at 50, 60 and 70 DAT, number of filled grain $panicle^{-1}$ (154.198), 1000 seed weight (20.49 g), grain yield (3.36 t ha^{-1}) and harvest index (25.85%) were recorded from Zn_3 (20 kg Zn ha^{-1}) and the highest non-effective tiller $hill^{-1}$ (6.68), total tillers $hill^{-1}$ (14.80) and un-filled grain $panicle^{-1}$ (25.62) was recorded from Zn_1 (Control). On the contrary, the shortest plant (84.87 cm), lowest number of panicle m^{-2} (93.02), shortest panicle length (25.66), lowest number of filled grains $panicle^{-1}$ (127.23), grain yield (2.95 t ha^{-1}) and harvest index (23.47%) was obtained from Zn_1 (0 kg Zn ha^{-1}).

In case of interaction effect of Boron and Zinc, the tallestt plant height (92.91 cm), panicle length (28.30 cm), number of filled grain panicle^{-1} (186.1), number of total grain panicle^{-1} (203.1), grain yield (4.93 t ha^{-1}), harvest index (35.59%) was recorded from B_3Zn_3. Where the highest number of non-effective tiller hill^{-1} (8.25) was recorded from the treatment combination of B_3Zn_1 and the highest number of un-filled grain panicle^{-1} (31.00) was observed from B_3Zn_1 (10kg B ha^{-1} and 0 kg Zn ha^{-1}). In another consideration, the shortest plant (82.13 cm) was achieved by B_1Zn_1, the lowest number of panicle (87.11 cm) was obtained from B_1Zn_1, the lowest number of effective tiller hill^{-1} (2.56) was found in B_1 Zn1, the lowest number of filled grains panicle^{-1} (111.2) from B_4Zn_4, the lowest grain yield (2.26 t ha^{-1}) was from B_3Zn_1, the lowest harvest index (21.19%) was achieved from B_2Zn_2. At 50, 60 and 70 DAT, the highest grain weight (0.029, 0.032 and 0.0390 g, respectively) was found from the treatment combination of B_3Zn_4 (10 kg B ha^{-1} and 20 kg Zn ha^{-1}), whereas the lowest grain weight (0.011, 0.019 and 0.0130g, respectively) was observed from the treatment combination of B_1Zn_1 (0 kg B ha^{-1} and 0 kg Zn ha^{-1}) at same DAT.

From the above findings, it can be concluded that the highest performance regarding grain growth rate, yield and yield contributing characters the effect of B_3Zn_3 (B_3 = 10 kg B ha^{-1} and Zn_3 = 15kg Zn ha^{-1}) gave the highest grain yield. So, this can be treated as the best treatment combination compared to others and can be used for obtaining the highest grain of boro rice variety *Tia*.

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APPENDIX

APPENDIX

Appendix 1. Morpho-physio-chemical properties of HSTU, Dinajpur soil with critical value and their extraction methods

Morphological soil properties			
Properties	Nutrient status	Critical value	Extraction methods
AEZ	AEZ-1: Old Himalayan Piedmont Plain		
Land type	High land		
General soil type	Non-calcareous brown floodplain sols		
Soil series	Ranisankil		
Topography	Levelled		
Drainage	Well drainage system		
Flood level	Above flood level		
Geographic position	25.42^o North Latitude 88.39^o East Longitude 37.35m above sea level		
AEZ	AEZ-1: Old Himalayan Piedmont Plain		
Physiological soil properties			
Properties	Value (%)	Critical value	Extraction methods
Sand	58		
Silt	28		
Clay	14		
Textural class	Sandy loam		Hydrometer method (Black, 1965). Determined by Marshall's Triangular coordinates by USDA system.

Chemical soil parameters			
Soil pH (1:1.25, Soil:H_2O)	5.41	-	Glass-electrode pH meter with 1:1.25 soil-water ratios (Page *et al.*,1982).
Organic matter	1.48		Wet oxidation method (Black, 1965). Calculated by Van Bemmelen factor 1.73 (Piper, 1966).
N (%)	0.08		Micro-Kjeldahl method (Bremmer and Mulvaney, 1982).
Available P (ppm)	11.20		Molybdate blue ascorbic acid method (Bray and Kurtz, 1945).
Exchangeable K (meq %)	0.10		Determined by Flame photometer
Exchangeable Ca (meq %)	2.48		By Atomic Absorption Spectrophotometer (AAS) (Knudsen *et al.*, 1982).
Exchangeable Mg (meq %)	0.29		Extractable method (Hunter, 1972).
Available S (ppm)	17.29		Turbidity method using $BaCl_2$ (Fox *et al.,* 1964).
	0.13		Mono-calcium bi-phosphate method

Available B (ppm)			and the determination by spectrophotometer following Azomethine –H method (Page *et al.* 1982).
Available Zn (ppm)	0.90		Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978).
Available Fe (ppm)	51.90		Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978).
Available Mn (ppm)	12.13		Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978).
CEC			Sodium acetate saturation method (Rhoades, 1982).

Source: Department of Soil Science, HSTU, Dinajpur.