COMBINED EFFECT OF SULPHUR AND BORON ON GROWTH, YIELD,OIL AND NUTRIENT CONTENT OF MUSTARD (BARI SHARISHA-9)

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CERTIFICATE

This is to certify that thesis entitled, "COMBINED EFFECT OF SULPHUR AND BORON ON GROWTH,YIELD,OIL AND NUTRIENT CONTENT OF MUSTARD (BARI SHARISHA-9)".submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in AGRICULTURAL CHEMISTRY, embodies the result of a piece of bona fide research work carried out by **Arshul Azam**, Registration No. **09-03655** 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.

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DEDICATED TO MY ADORED PARENTS

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COMBINED EFFECT OF SULPHUR AND BORON ON GROWTH AND YIELD OF MUSTARD (BARI SHARISHA- 9)

ABSTRACT

This experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Dhaka to know the Combined effect of different levels of Sulphur and Boron on yield and yield contributing characters of "BARI sharisha-9" mustard as well as the nutrient content and their uptake by mustard plants and seeds. The experiment consisted of two factors namely, four Sulphur levels (0, 10, 20 and 30 kg S ha^{-1}) and four Boron levels (0, 1, 2 and 3 kg B ha^{-1}). It was replicated thrice in a randomized complete block design. The Combined effect of Sulphur and Boron exerted significant influence on most of the selected characteristics viz. plant height (cm), number of branches $plant^{-1}$ (no.), pod length (cm), capsule $plant^{-1}$ (no.) seed $capsule^{-1}$ (no.), 1000 seed weight (g), grain yield (t ha^{-1}), stover yield (t ha^{-1}), harvest index (%), oil content in mustard and N, protein, K, P, S, B content in stover and seed. The highest grain yield (2180 kg ha^{-1}) was obtained for the Combined effect of S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}) because of production of the highest number of capsule $plant^{-1}$ (241.3 no) and seed per capsule (15.75 no). Results revealed that highest oil content (45.01%) in mustard was recorded for S3B3 treatment (30 kg S ha^{-1} and 3 kg B ha^{-1}), which was statistically identical from the result (43.80%) found for S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}). Considering the Combined effects of Sulphur and Boron on selected parameters, the treatment S2B3 (20 kg S ha^{-1} and 3 kg B ha^{-1}) could be suggested for "BARI sharisha-9" cultivation in agro-ecological zone of Tejgaon, Dhaka.

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CHAPTER I

INTRODUCTION

Mustard is one of the important oilseed crops grown in Bangladesh, covers almost 60% of the total oil seed demand (BBS, 2007). The annual production of mustard is 3.34 lac metric tons from the area of 3.52 lac hectare against the total oilseed production of 5.48 lac tons (BBS, 2011).According to Chowdhury and Uddin (1990), local production of mustard oil meets nearly 25% oil requirement of Bangladesh. The average yield of mustard oilseed is very low in Bangladesh compared to other countries. The low production of mustard oilseed may be attributed to genetical, environmental conditions, poor agronomical including fertilizer management. The production of mustard is not properly exploited because lac of proper information about the nutritional requirements. Usually, farmers use local variety Tori-7 in Bangladesh with their own fertilizer management including lower amount of NPK instead of using sulfur and Boron fertilizer, which is another cause of very low yield of mustard. However, various research organizations has developed high yielding mustard varieties like BARI sharisha-8, BARI sharisha-9 and BARI sharisha-11. Therefore, developing new high yielding varieties with proper fertilizer management can increase the productivity of mustard oilseed crop in Bangladesh. This will help increasing the present yield of mustard, and thus it will reduce the difference between present production and the requirement. The edible oil demand is increasing day by day because of increasing population. Therefore, it is expected that the production of edible oil should be increased to meet the demand through increased mustard yield.

Generally, Sulphur is considered as major nutrient for the proper growth of mustard plant. Mustard is highly susceptible to S-shortage and responds well to S-fertilization (Haque, 2000). It has been reported that S greatly influenced the synthesis of amino acids (cystine, cysteine and methionine), co-enzymes (biotin, coenzyme A, pyrophosphate, lipoic acid and thiamine) and some secondary metabolites. Application of Sulphur also helps in chlorophyll formation and enhances vegetative growth. Sulphur is considered as most important fertilizer for the cultivation of mustard, which plays a vital role to increase the yield including oil content. It is also responsible for the quality of mustard oil by increasing protein content and several fatty acids (Aulakh and Pasricha, 1997). Moreover, Sulphur application influences the uptake of nitrogen, phosphorous and potassium. In general, 97% soils of Bangladesh are deficient in Sulphur and this deficiency is increasing

day by day because of using Sulphur free fertilizer. Hence, it is desirable to know the effect of Sulphur on the yield of mustard with oil content.

Boron (B) deficiency in soils is another problem in cultivation of oil seed crops and about one million hectare of land has Boron deficiency problem causing low yield of oil seeds (Islam *et al.*, 1999). Rate of water adsorption and carbohydrate translocation in plant are restricted because of Boron deficiency in soil. According to Robinson (1973), total amount of Boron concentration in seed and stem of oilseed crops is at third place among micronutrients. Boron helps in the absorption of N, P and K. Consequently, Boron deficiency affects the equilibrium state of these three macronutrients.

As observed by Dutta *et al.* (1984) and Islam and Sarker (1993), Boron application markedly increases pod number and seed set. The yield of mustard is greatly influenced by Boronparticularly where soil is deficient in Boron. Seed yield increases ranging from16-69% due to Boron application. Boron is greatly involved in the synthesis of protein and oil (Malewar *et al.*, 2001). It is also found that essential amino acid increased with increasing Boron supply in soil (Lqtidar and Rahman, 1984).

Several researches have been carried out on the effect of N, P and K fertilizers on mustard and other oil seed crops. But a few research works have been done to know effect of Sulphur and Boron on production of oil seed crops in Bangladesh, although it has been reported that Sulphur and Boron are very effective to increase the yield of oil seed crops in many countries around the world. The above discussion suggests that the limiting nutrients need to be identified in order to increase the production of mustard yield and nutritional value of mustard oil. Keeping the above mentioned facts in mind, this study was undertaken with the following specific objectives.

1. to compare the growth and yield performance of BARI sharisha-9 by using different doses of Sulphur and Boron
2. to know the combined effect of Sulphur and Boron on nutrient content and uptake by plant and seeds of mustard
3. to identify the suitable doses of Sulphur and Boron for better yield of mustard
4. to study the effect of S and B on the chemical composition and oil content of mustard and
5. to observe the combined effect of Sulphur and Boron on the chemical composition and oil content of mustard.

CHAPTER II

REVIEW OF LITERATURE

2.1 Preamble

Review of literature in any research is very necessary because it provides a scope for reviewing the stock of knowledge, primary concept and relevant information to the proposed research. These knowledge, concept and information give a guideline in designing and conducting the research successfully. It is essential for reviewing that gives a proper instruction in designing a future research problems and validating the new findings.

Mustard in one of the most important oilseed crops in Bangladesh. It plays important role to mitigate the shortage of healthy edible oil demand of the country. But the production rate of mustard is still low than other mustard producing countries of Asia because of various reasons. Poor fertilizer management is one of possible reasons of low yield of mustard, which influence the yield directly. But the yield of mustard can be increased by applying proper fertilization management. Though, several investigations on the effect of Sulphur and Boron on yield of mustard have been carried out in many countries of the world. But the effect of Sulphur and Boron on growth, yield, nutrient uptake, nutrient and oil content of mustard is rare one in Bangladesh. In present part, the most common and fruitful relevant studies on mustard yield, fertilization management for oilseed crops including mustard are given, which were conducted in Bangladesh and abroad in the recent past.

2.2 Production and nutrient content of mustard

The decreasing rate in oil production in Bangladesh was significant because of replacement of oilseed crop area by HYV Boro rice production by the pressure of high population (Akhtaruzzaman *et al.*, 2001 and Jahan *et al.*, 2009).

Rahman *et al.* (2009) reported that both acreage and total production of oilseeds decreased continuously from 2000-2001 to 2005-2006 and reduction in acreage was found 18.59%.

According to BBS (2011), total production of oilseed in Bangladesh was 716 thousand metric tons that couldn't satisfy the demand of oil consumption. Therefore, the country

imported 116833.767 metric tons of oilseeds in the fiscal year of 2010-2011 to mitigate the crisis.

Mondhal and Wahhab (2001) investigated the production technology of oil crops in Bangladesh. They reported that mustard seeds contain 40-45% oil and 20-25% protein that plays vital role in keeping good health.

2.3 Effect of Sulphur on growth and yield of oilseed crops

Sulphur is one of the macronutrients occurring in the soil both in organic and inorganic forms and performs important functions in plant growth. Sulphur is a constituent of cysteine and methionine amino acid and absorbed by roots for being utilized by the aerial parts of plant. Sulphur imparts protein stability via formation of -S-S- bridges and plays important role in regulating redox and acid-base reactions in plant.

Tripathi *et al.* (2007) conducted a field experiment during 2003 to 2005 on Sulphur deficient clay loam soil. Four levels of Sulphur were applied to sesame cv. JTS-8 through single super phosphate, elemental Sulphur and gypsum. The results revealed that growth, yield attributes and yield were influenced with increasing levels of Sulphur. Application of 45 kg S ha^{-1} through single super phosphate was found more economical followed by 30 and 15 kg S ha^{-1}. Single super phosphate was found to be a relatively better source of Sulphur than gypsum and elemental Sulphur.

Maragatham *et al.* (2006) studied the effects of S fertilizer (S material from Cochin Refineries) on the performance of sesame (cv. Co 1 karosathena) in Coimbatore, Tamil Nadu, India, during 2000, S at 40 and 60 kg ha^{-1} gave comparable yields, whereas S at 80 kg ha^{-1} registered a lower yield, indicating that 40 kg S ha^{-1} was optimum for sesame. The seed oil content was not markedly affected by the various amendments. The application of 40 kg S ha^{-1} increased the seed oil content over control from 47.63 to 49.83%. Among the treatment combinations, 40 kg S ha^{-1}applied with FYM + Thiobacillus increased the seed oil content by 3.7%. The protein content increased by 3.3% following the application of 40 kg S ha^{-1}, and by 7.4% following the application of S + FYM + Thiobacillus. [1.0 quintal=100.0 kg].

Singh and Prasad (2003) conducted field experiments during the 2001-03 *kharif* seasons in Jharkhand, India, on soybean cv. Birsa. The seed and stover yields of soybean were significantly influenced by graded levels of S and B application. The crop yield increased more due to S compared to B application. The S x B treatment revealed that maximum

seed yield was obtained with 60 kg S and 2.0 kg B ha^{-1}. The total S and B uptake by crop increased significantly with increased levels of up to 60 kg S + 2.0 kg B ha^{-1}. The total S uptake at 0 and 60 kg S ha^{-1} was 10.27 and 16.72 kg ha^{-1}, respectively, whereas total B uptake at 0 and 2.0kg B ha^{-1} was 98.58 and 198.72 kg ha^{-1}, respectively. The oil and protein contents in soybean seed increased with successive increase of S and B levels. Increasing levels of S significantly increased the protein content in soybean seed. The maximum protein content (37.79%) in seed was recorded at 40 kg S + 0.5 kg B ha^{-1}.

Sriramachandrasekharan (2004) showed the effects of S (0, 15, 30 or 45kg ha-1 through gypsum) and poultry manure (10 t ha^{-1}) on the yield and Sulphur uptake and use efficiency of sesame cv. TMV3 was studied in Annamalainagar, Tamil Nadu, India, during 2001. The apparent S recovery (15.8 and 12.9) and physiological efficiency (67.4 and 56.2 [kg grain kg^{-1} S uptake]) were highest at 15 kg ha^{-1}, decreasing with further increase in S rate.

Sharma *et al.* (2001) carried out a study to determine the effect of S on the growth and yield of selected rainy season crops such as cowpea, cluster bean, pearl millet, castor and sesame in Rajasthan, India, during the rainy season. They found that Sulphur level lengthen the height of all tested crops. Increasing rates also increased the dry matter accumulation per plant. Supply of Sulphur also promoted floral primordial initiation, resulting in higher number of pods (or earheads) per plant and seed number per pod or (earhead), and ultimately in enhanced seed yield. Application of S had positive effects on the yields of all crops.

Vaijapuri *et al.* (2003) evaluated the effects of Sulphur (0, 15, 30 and 45 kg ha^{-1}) and organic amendments (10 t ha^{-1} each of farmyard manure, poultry manure and press mud) on the seed quality and nutrient uptake of sesame cv. TMV 3. They found that application of 45 kg S ha^{-1} gave the best result in terms of seed quality, yield and yield attributing characters and nitrogen, phosphorus, potassium and Sulphur uptake. Application of poultry manure resulted in the highest oil content oil yield and crude protein content of sesame.

Sharma and Gupta (2003) stated that sulfur has a great influence on the growth and yield of sesame. Treatments comprised four Sulphur rates (0, 20, 40 and 60 kg ha^{-1}). Application of sulfur at 40 kg ha^{-1} increased the height and dry matter accumulation. Floral primordial initiation higher number of pods $plant^{-1}$ and seed number $capsule^{-1}$ and ultimately enhanced seed yield of sesame up to 27% over control. 60 kg ha^{-1}which also

gave statistically same result as 40 kg S ha^{-1}.

Sarkar *et al.* (2002) carried out a field experiment during spring of 1999 and 2000 to study the effects of planting geometry (30 x 30, 45 x 15, and 45 x 30 cm), row orientation (east-west and north-south), and Sulphur rate (0, 25, and 50 kg ha^{-1}) on the growth and productivity of sesame cv. B 67. Sowing was carried out on March 12, 1999 and 14 March 2000 after winter rice. Sesame matured in 90 days and was harvested in the first fortnight of June. Planting in north-south direction and applying 25 kg S ha^{-1} were more effective in improving leaf area index, crop growth rate, relative growth rate, net assimilation rate, yield attributes, and crop yield than planting in east-west direction and applying 50 kg S ha^{-1}.

Allam (2002) studied the effects of gypsum (0, 500, and 1000 kg $feddan^{-1}$) and spacing (10, 20, and 30 cm) on sesame cv. Giza 32 in Assiut, Egypt, in 2000 and 2001. Gypsum was applied during sowing and 55 days after sowing. Increasing gypsum, rates increased plant height, length of fruiting zone, number of branches and capsules per plant, seed yield per plant.

A field experiment was conducted by Dayanand *et al.* (2002) to study the effects of Sulphur on nutrient uptake, yield and food value of sesame (*S. indicum*). The nitrogen content of straw, the total nitrogen uptake and oil yield of sesame increased significantly up to 40 kg S ha^{-1}. Biomass production, nitrogen content, seed yield, straw yield, protein and oil content of sesame significantly increased up to 60 kg S ha^{-1}.

Sarkar and Banik (2002) measured the effect of Sulphur (at the rate of 0, 25 and 50 kg S ha^{-1}) on the growth and productivity of sesame cv. B67 and found that planting in north south direction and applying 50 kg S ha^{-1} were effective in improving leaf area index, crop growth rate, relative growth rate, net assimilation rate, yield attributes and crop yield than planting in east-west direction and applying 25 kg S ha^{-1}.

Radhamani *et al.* (2001) carried out a field experiment in Tamil Nadu, India, during summer of 2000 to study the effect of 100 ppm salicylic acid (SA); 100 ppm Mepiquat chloride (MC); 0.5% Potassium chloride; 100 A or MC + 0.5% Potassium chloride; and 20 kg S (gypsum) ha^{-1}on the yield and oil content of sesame.

Radhamani *et al.* (2001) studied the effect of different level of Sulphur on seed yield of sesame and found that 20 kg Sulphur (gypsum) ha^{-1} singly gave the tallest plants and the highest dry matter production with 100 ppm salicylic acid (SA). At harvest, the tallest

plants were recorded for 20 kg S ha^{-1} at 100 ppm SA + 1.5% potassium chloride while 20 kg S ha^{-1} singly or in combination with 100 ppm SA and 100 ppm SA + 0.5 potassium chloride and 20 kg S ha^{-1} + 100 ppm SA + 0.5% potassium chloride gave the highest number of capsules $plant^{-1}$, number of seeds $capsule^{-1}$, seed yield and oil content.

Ghosh *et al.* (2000) observed that the response of Sulphur application in oilseed crops is markedly, ranging from 15 to 62 kg S ha^{-1} depending on soil type. Applications of Sulphur increase the number of capsule $plant^{-1}$, number of seeds $capsule^{-1}$and oil content of seed markedly. Gypsum has been found an effective source of Sulphur of oilseed crops like sesame, groundnut and castor. In addition this, water problem is the major constrains in oilseed crop. Most of the oilseed crop plants are very sensitive to water logging and scarcity of water. Regular rainfall with poor drainage made the plants susceptible to seedling rot diseases.

Meng *et al.* (1999) studied the effects of Sulphur application sesame and rapeseed in field trials in 1997 in Zhjiang Chaine. They applied Sulphur at the rate of 0, 20 or 40 kg ha^{-1} as gypsum and found that application of Sulphur increased seed yield of sesame and rape and soil available Sulphur with SSP giving the best results. Sulphur fertilization significantly increased the contents of nitrogen, Sulphur and oil in sesame seeds.

Raja and Sreemannarayana (1998) observed that pulse and oilseed crops showed responses to applied Sulphur, the magnitude of response being dependent on native status. Sesame and sunflower showed highest response with applied Sulphur. Sesame crops required application of 40 and 60 kg S ha^{-1} in Vertisol and Alfisol soil. The seed yield of the crops were maximum when N:S ratio in plant was 10:4. Sesame showed a response at to 60 kg S ha^{-1} applied as gypsum. Sulphur application also improved the crude protein content and oil contents of seed.

Thorve *et al.* (1997) in a field experiment evaluated the yield and yield attributing characters of three sesame cultivars on the same management level and found that cv. Tapi, Phule and Hawari (local) produced seed yields of 0.95, 0.91 and 0.52 t ha^{-1}respectively.

Chaplot (1996) stated that application of Sulphur at 50 kg ha^{-1} with 40 or 60 kg P_2O_5 gave the best growth and yield of sesame (*S. indicum* L.). Phosphorus singly has no significant effect on oil content of sesame but Sulphur has. The highest net return and benefit cost ratio was obtained with the application of Sulphur in at 50 kg ha^{-1} in combination with 40

kg P_2O_5 ha^{-1} as DAP.

Chaplot *et al.* (1992) stated that yield of sesame cv. TC 25 grows at Udaipur; India was 0.66 t ha^{-1} with the application 0 kg S ha^{-1} whereas it was significantly high 0.76 t $ha^{-1}$when receiving 50 kg S ha^{-1}. The residual effects of Sulphur in the next season wheat increased the grain yield markedly.

Najeeb (1987) compared the performance of oil seed (sesame, castor and sunflower) and pulses (black gram, cow pea and green gram) crops on alfisol with an available S content of 8.2 mg kg^{-1}. Application of 20 kg S ha^{-1} in pulse and sesame resulted in significantly higher yield over control.

2.2 Effect of Sulphur on nutrient and oil content of oilseed crops

Sharma *et al.* (2001) conducted a field experiment on the effect of Sulphur on protein accumulation in mustard. Application of Sulphur 75kg ha^{-1} in form of SSP found to be the best treatment for increasing protein content of soybean.

Babhulkar *et al.* (2000) carried out an experiment on effect of Sulphur fertilizer on protein content of safflower. They reported that Sulphur greatly influenced the protein synthesis in seeds of safflower.

Abraham (2000) reported, from a treatment combinations of 40 or 60kg S, and 100 or 150kg N ha^{-1}, that soluble protein content and rate of photosynthesis, were the highest with 60kg S + 100kg N ha^{-1}. Protein content of mustard (*Brassica juncea* L. Czern and Cosson) increased significantly with the increase of S level from 0 to 90kg ha^{-1}. But the oil content of *Brassica campestris* was inversely related to the protein content in seed irrespective of levels of Sulphur.

Das and Das (1994) conducted a field experiment on the effects of four levels of Sulphur (0, 20, 40 and 60 kg ha^{-1}) on sunflower. They found that highest S rate of 60kg ha^{-1} increased the oil and protein content of sunflower over that of the control.

2.3 Effect of Boron on growth and yield of oilseed crops

Boron is important macronutrient and plays a vital role in the physiological processes of plants such as cell maturation, cell elongation and cell division, carbohydrate, protein and nucleic acid metabolism, cytokinin synthesis, acid and phenol metabolisms. The primary functions of Boron are extra-cellular and related to lignification and xylem

differentiation.

Liu *et al.* (2003) studied the effects of Mo and B, alone or in combination, on seed quality of pot growth soybean cultivars Zhechum 3, Zhechun 2, and 3811. Application of Mo and/or B increased the content of protein, in dispensable amino acids, total amino-acids (excluding proline), N, P, K and decrease the content of Calcium and oil.

Deasarker *et al.* (2001) studied the effect of Boron on the yield of soybean. They applied two doses of Boron (4 and 6 kg B ha^{-1}) in production of soybean. Boron dose of 2kg $ha^{-1}$was found the best among the Boron treatments for increasing soybean yield.

Hemantaranjan *et al.* (2000) conducted a field experiment on soybean. Plant height, root length, chlorophyll-B content, total dry matter production and seed yield of soybean were higher at 50 than 100 ppm B. However, chlorophyll-A content was higher at 100 ppm B. The combined application of S and Fe significantly increased shoot height, root length, number of leaves per plant, leaf area per plant, total dry matter production and seed oil content, with 80 + 20 mg per kg soil giving the best results.

Hua and Yan (1998) stated that the addition of Boron promoted elongation of epicotyle and hypocotyle of mungbean and increased seedling height and dry weight in the Al treated plant.

Talashilkar and Chavan (1996) observed that pod production of groundnut was enhanced significantly with the addition of B by 44 percent. The maximum pod and haulm yields were recorded in the treatment receiving B through Boronated super phosphate along with application of FYM, N and P.

In a field study with B deficient soil growing chickpea cv. Kaliaka and applying no fertilizer, complete fertilizer (P, K, S, B, Zn, Mo, Cu, Mn and Fe) or the complete fertilizer minus each of the trace elements. Srivastava *et al.* (1996) observed that flower abortion was highest and no. seed was produced in the treatment given no. B.

Ramirez and Linares (1995) reported sesame was exposed to 6.25-750 µg B $litre^{-1}$. Dry matter production of leaves, stems and roots were severely decreased when B in the leaf tissue was below 21 µg g^{-1}.

Sakal *et al.* (1994) evaluated the direct and residual effect of varying levels of B (0, 8, 16, 32 and 64 kg Borax $ha^{-1}$and FYM (0.25 and 5.0 t ha^{-1}) alone and in combinations on crops in maize-lentil cropping system. Increasing levels of B up to 16 kg borax ha^{-1}significantly

increased and higher levels decreased the yield of first crop. Application of 16 kg Borax ha^{-1} in conjunction with 5 t FYM $ha^{-1}$was an ideal combination, which appreciably enhanced the cumulative grain yield response.

Sindoni *et al.* (1994) grew *Sesamum inclicum* in Hoagland No. 2 nutrient solution supplemented with 0.05 mg B $liter^{-1}$ or throughout the growth or until 20-30 or 40-day-old when B was either reduced to 0.25 mg l^{-1} or eliminated completely. Elimination of B at all ages reduced root and shoot dry weight but reduction of B supplementation significantly reduced dry weight only at 30 day. Reduction of B concentration significantly decreased seed production and concentration of B in leaves stems and pods. Seed weight was linearly and significantly correlated with concentration of B in pods.

Singh and Singh (1994) noted that green pod yield of French beans increased with increase in P application and with B application up to 1 kg B ha^{-1}. Application of more than 1 kg B ha^{-1} caused a toxic effect.

Posypanov *et al.* (1994) stated that applying 1 kg B ha^{-1} to peas and soybeans and treating seeds whit the equivalent of 50 g ammonium molybdate ha^{-1} increased nodule weight, atmospheric N_2fixation and seed yield.

In the field experiments borax solution at 0.2% was sprayed at seedling and flowering growth stages. In the pot experiments boric acid at 0.7 ppm was given and in hydroponic experiments 0.01, 0.02, 0.2 and 2.0 ppm boric acid were applied. Average yield increases of 4.6 -21.2%, 3.3-19.9% and 2.1 -17.1 % were obtained with B application for Zhongzhi 8, Golden Turkey and Qingma, respectively. Application of rates higher than 0.20ppm in the hydroponic experiments was detrimental, depressing growth of or even causing death to the plant (Li *et al.*, 1992).

Roy *et al.* (1992) observed that soil application of 20kg borax ha^{-1} increased seed yield of lentil, while soil application of 3 kg sodium molybdate ha^{-1}gave only small (about 14%) increase.

Sinha *et al.* (1991) studied the response of five kharif crops, viz. onion, groundnut, maize, sweet potato and yard long bean as well as five *rabi* crops, viz. mustard, onion, lentil, maize and sunflower to Boron application on Boron deficient calcareous soils under field condition. Boron was applied as borax @ 0, 1.5 and 2.5 kg B ha^{-1}. All the crops responded to Boron, but the magnitude of yield response differed from crop to crop. The optimum level of B for khari*f* as well as rabi crops was 1.5 kg ha^{-1}.

Sakal *et al.* (1990) observed that seed yield of chickpea increased from 1.4 t ha^{-1} with no B to 1.49 t $ha^{-1}$with 3 kg B ha^{-1} . The yield response of B application was greater on low B soils. It was concluded that on soils containing <0.35 ppm B. 3 kg B ha^{-1} was optimum and on soils containing >0.35 rpm B, 2 kg B ha^{-1} was optimum.

Rerkasem *et al.* (1989) reported that wheat growing in the low Boron soils exhibited symptoms of male sterility, which included poorly developed anthers and nonviable pollen grains. Grain set failure lower seed yield and male sterility symptoms were associated with low Boron concentration in the flag leaf Failure in grain set up to 100% of florets was frequently observed. They also reported that poor grain set in wheat depressed seed yield by 4050% on Tropaqualf soils having low Boron content (0.08-0.12 mg kg^{-1}).

Sakal *et al.* (1988) reported on a coarse textured calcareous soil that application of 2.0 and 2.5 kg B ha^{-1} increased grain yields of black gram and chickpea by 63 and 38%, respectively.

The effect of Boron on the development of the pollen grain of wheat was studied by Li *et al.* (1978) and Rerkasem *et al.* (1989). The process of fertilization involves the germination of the pollen grain and the growth of the pollen tube down the style into the ovary. In general, Boron deficiency produces pollen grains that are small and that do not accumulate starch. Pollens that develop normally may still be affected by Boron deficiency.

2.4 Effect of Boron on nutrient and oil content of oilseed crops

Tamak *et al.* (1997) observed in a field trial on sunflower cv. MSFH8 using 0, 30, 60 or 90kg P_2O_5 ha^{-1} or 0, 25 or 50kg S ha^{-1} along with 0.28ppm born sprayed or not sprayed. Seed yield increased significantly with up to 60kg P_2O_5 and 25kg S along with foliar application of Boron. Oil content of seeds was increased by all fertilizers, while protein content was increased by s but decreased by P and B.

Shen *et al.* (1993) conducted an experiment with rapseed using 0, 0.3, 0.6 or 1.0ppm Boron. Boron application remarkably increased yield and the contents of soluble protein.

Ramchandra *et al.* (1987) from a trial work, where Brassica campestris plants were grown under B deficiency (0.0033 and 0.0066ppm B) conditions, showed retarded growth, deformation of the young leaves. Boron deficiency decreased ribonucleic acid, protein contents and increased sugar, starch and phenol contents.

2.5 Effect of Sulphur and Boron fertilization on mustard

Sarker *et al.* (2002) investigated the effect of Sulphur and Boron on yield, quality and nutrient uptake by Bangladesh Soybean-4. They applied five levels of both Sulphur and Boron (0, 10, 20, 30 and 50kg S ha^{-1} and 0, 0.5, 1.0, 2.0 and 4.0kg B ha^{-1}). Sulphur and born significantly influenced the yield and yield attributes when applied individually, but significant effect of their combined was not observed on yield of Soybean-4. They stated that Sulphur (30kg ha^{-1}) and Boron (1.0kg ha^{-1}) alone or in combination could be applied in production of Soybean-4.

Kaisher *et al.* (2010) observed the effects of Sulphur and Boron on seed yield and protein content of mungbean, variety BARI mung-5. They found that combined fertilization of Sulphur (30kg ha^{-1}) and Boron (5kg ha^{-1}) significantly increased plant height, number of branches, number of pods, number of seeds per pod, seed quality as dry matter and protein content of mungbean.

Huq (2012) studied the effect of Sulphur and Boron on seed yield of sesame (*Sesamum indicum* L.). Four levels of Sulphur (0, 10, 20 and 30kg ha^{-1}) and Boron (0, 1, 2 and 3kg ha^{-1}) were applied in this research work. They found maximum sesame seed yield from the combined of 20 kg S ha^{-1} and 3 kg B ha^{-1}. Maximum number of capsule per plant, maximum number of seed per capsule and highest length of capsule were also observed as combined fertilization of Sulphur (20 kg ha^{-1}) and Boron (3 kg ha^{-1}).

Karthikeyan and Shukla (2008) studied the effect of combined of Boron and Sulphur on nutrient uptake and quality parameters of mustard (*Brassica juncea* L.) and sunflower (*Helianthus annuus* L.). Significant combined effect of Boron and Sulphur on dry matter and seed yields of both crops was observed. They also revealed that combined of Sulphur (60mg kg^{-1}) and Boron (2mg kg^{-1}) influenced significantly the oil and protein content of mustard and sunflower.

Effect of Sulphur, zinc and Boron on yield, economics and nutrients uptake of mustard was observed by Verma *et al.* (2002). They used Sulphur (0, 20, 40 and 60 kg ha^{-1}), zinc (0, 5 and 10 kg ha^{-1}) and Boron (0, 0.5 and 1.0 kg ha^{-1}) separately and in combination. Quality, economics and uptake of nutrients were influenced with the increase of dose of each fertilizer. On economic basis, they recorded highest profit with the combined use of Sulphur (60kg ha^{-1}), zinc (5kg ha^{-1}) and Boron (1kg ha^{-1}).

From the above review of literature, it is noticed that different levels of dose of Sulphur and Boron exerted a profound influences on yield and yield contributing characters and oil content of oilseed crops. The various physio-chemical properties of soil are also influenced by the application of S and B. Most of the authors showed that increasing Sulphur and Boron level increased grain yield and oil content if the soil lacks the nutrient.

Considering the available information so far collected from home and abroad, the present study was designed to investigate the effect of combined of Sulphur and Boron on growth, yield, chemical composition and oil content of mustard under the Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University.

CHAPTER III

MATERIALS AND METHODS

This chapter comprises a brief description on experimentation including duration, soil, climate, geographical region, land preparation, design, layout, intercultural operations, data collection and data analysis which are stated below.

3.1 Location of the experimental plot

The experiment was conducted at the Central Farm of the Sher-e-Bangla Agricultural University, Dhaka during the period from November, 2014 to February, 2015. The site is 90.2^{O}N and 23.5^{0}E Latitude and at an altitude of 8.2 m from the sea level.

3.2 Characteristics of soil

The soil of the experimental field was Non- calcareous, dark gray, high land belonging to the Modhapur Tract (AEZ No-28). The soil texture was silty loam with a pH 6.7. Soil samples of the experimental plot was collected from a depth of 0 to 30 cm before conducting the experiment Soil analyzed in the Soil Resources Development Institute (SRDI) Farmgate Dhaka. The experimental site was a medium high land.

3.3 Climatic condition

The experimental area under the sub-tropical monsoon climate was characterized by heavy rainfall in the Kharif season and scanty in the Rabi season (October to March). There was no rainfall during the month of October, November, December and January. The average maximum temperature during the period of experiment was 31.82°C and the average minimum temperature was 28.14°C. Details of the meteorological data in respect of temperature, rainfall and relative humidity during the period of the experiment were collected from Weather Station of Agargong, Dhaka.

3.4 Agro-ecological region

The experimental field belongs to the agro-ecological region of the Modhupur Tract (AEZ-28). The landscape comprises level upland, closely or broadly dissected terraces associated with either shallow or broad, deep valleys.

3.5 Experimental materials

"BARI sharisha-9", a new high yielding variety of mustard developed by Bangladesh Agriculture Research Institute (BARI), Gazipur has been used as experimental material.

3.6 Experimental treatments

Treatments were as follows:

A. Sulphur level (kg ha^{-1})

1) S_0 - 0 (control)
2) S_1 - 10
3) S_2 - 20
4) S_3 - 30

B. Boron level (kg ha^{-1})

1) B_0 - 0 (control)
2) B_1 - 1
3) B_2 - 2
4) B_3 - 3

3.7 Experimental design and layout

The experimental treatments were laid out in Randomized Complete Block Design (RCBD) with three replications. The experimental unit was divided into 3 blocks with 16 unit plots of $5m^2$(2m x 2.5 m) size in each block. Thus the total numbers of unit plots were 3x 16 = 48. The distance maintained between two unit plots was 0.5 m and that between blocks 1.0 m.

3.8 Conduction of the experiment

3.8.1 Land preparation

The land was prepared by country plough. The land was prepared by ploughing and cross ploughing followed by laddering. The corner of the land was spaded and visible large clods were broken into small pieces. Weeds and stubbles were removed from the field. The layout of the experiment was done in accordance with the design adopted. Finally, individual plots were prepared by using spade before sowing seeds.

3.8.2 Fertilizer treatment under investigation

There were 6 fertilizer treatments. The rate of 120 kg Urea ha^{-1}, 145 kg TSP ha^{-1}, 45 kg MOP ha^{-1}, 5 kg $ZnSO_4$ ha^{-1} was applied to all plots. There were 4 doses of Sulphur (0, 10, 20, 30 kg S ha^{-1}) and 4 doses of Boron (0, 1, 2, and 3 kg ha^{-1}). Gypsum and boric acid were used as the sources of Sulphur and Boron.

The whole amount of triple super phosphate (TSP), muriate of potash (MOP), zinc sulphate and 50% of Urea were incorporated at the time of final land preparation. Gypsum and Boric acid were applied as per treatment. The remaining Urea was applied at 25 days after seed germination.

3.8.3 Sowing of seeds

Seeds of mustard were sown on the 7th November, 2014 in 2-3 cm deep furrows made by hand rake keeping 25 cm distance from row to row. After placement of seeds in furrow, seeds were covered with soil followed by a light pressure by hand. The seed rate was 6 kg ha^{-1}.

3.8.4 Emergence of seedlings

Seedling emergence started after 3 days and completed within 7 days of sowing. After establishment, on 21November, 2014 keeping the healthy seedlings within a distance of 5 cm, the remaining seedlings were carefully uprooted by hand pulling.

3.8.5 Intercultural operation

3.8.5.1 Weeding

The experimental field was weeded on 20 and 35 days after sowing. The weeding was done manually with Nirani.

3.8.5.2 Insecticide application

The crop was infested by pod borer *(Heliothis armigera)* at reproductive stage. It was successfully controlled by spraying insecticide Sumithion 50EC at the rate of 1 L ha^{-1}

3.9 Harvesting and collection of experimental data

Five Sample plants per plot were first collected just before crop harvesting, which was done on the 10 February, 2015. All plant materials were carried carefully to the

farmhouse building for collecting necessary data. For collecting data on seed and stover yield attributes five plants from each plot excluding border plants outside the central 1 m^2area, for taking yield data were selected randomly.

Data on the crop characters were as follows:

3.9.1 Plant height

The height of each sample plant was measured unit plot wise from the base to the tip of main stem of the five sample plants and then averaged.

3.9.2 Number of branches plant^{-1}(no.)

The number primary of branches plant^{-1} of each sample plant was counted unit plot wise from five sample plants and then averaged.

3.9.3 Capsule plant^{-1} (no.)

The number of capsule plant^{-1} were counted from the total capsule of 5 sample plants and then averaged.

3.9.4 Seed capsule^{-1} (no.)

The number of seed capsule^{-1} were counted from the three pods of each of 5 randomly selected plants taking one pod from bottom, another from middle and the rest from the top of the plant and then averaged.

3.9.5 1000-seed weight (g)

One thousand sun dried seeds were counted at random from the seed stock of sample plants. Weight of thousand seeds was then recorded by means of a digital electric balance.

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

The crop from middle portion (1 m^2) of each unit plot, which was kept for taking yield data was harvested, dried and then threshed separately. The entire quantity of seeds obtained from each unit plot was dried in the sun to bring them to normal storable state and the seed yield was recorded in terms of kg m^{-2}. Thereafter the yield was converted to t ha^{1}.After separating the seeds from the crop of the middle portion (1 m) of each plot, the Stover was sun-dried to constant weight and the Stover yield was recorded in terms of kgm^{-2} and it was converted into t ha^{-1}.

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

The crop was harvested at complete maturity as judged by visual observation. To obtain stover yield, the seed weight was subtracted from biomass recorded from each plot and obtained result was converted in ton per hectare.

3.9.8 Harvest index (%)

It denotes ratio of economic yield to biological yield and was calculated by the following formula described by Gardner *et al.*, 1985.

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

3.9.9 Determination of Nitrogen content

Nitrogen content was determined by Kjeldahl method as described by Ranganna (1998).

Working procedure

The Kjeldahl method consists of the following steps:

1. Digestion of the sample
2. Distillation
3.Titration

Digestion of the sample

The sample 10g was taken in weighing paper and measured accurately. This sample was poured into a 100 ml clean and dry Kjeldahl flask, to which 10g of Digestion Mixture and 25ml of conc. HCl were added. To avoid frothing and bumping 5 glass beads was placed inside the flask. A blank was carried with all reagents except sample material for the comparison. The flask was then heated in a Fume hood Digestion chamber at 400°C until the solution became colorless. At the end of digestion period, the flasks were cooled and diluted with 100 ml distilled water. A small piece of litmus paper was placed in the solution and the reaction was found to be acidic.

Distillation

The distilling set of Kjeldahl apparatus was thoroughly washed with distilled water before starting the distillation. In a measuring cylinder 60 ml of 40% NaOH was taken and it was carefully poured down the side of the Kjeldahl flask. The mouth of the flask was closed with a stopper containing connective tube, which was ultimately connected to the ammonia-receiving flask containing 25 ml receiver solution.

The mixture was boiled at such a rate that water and ammonia distilled over at a steady moderate rate. The heating process was not too slow or too fast so that the ammonia is being absorbed properly into the receiver solution.

Titration

The ammonia absorbed in the receiving flask containing receiver solution was titrated with 0.1N HCl. Similarly a reagent blank was distilled and titrated.

Calculation

Protein content of the sample on the percentage basis was calculated by the following formula:

$$\text{Nitrogen}\,\% = \frac{(\text{Sample titre} - \text{Blank titre}) \times \text{Normality of HCl} \times 14 \times \text{Volume made up} \times 100}{\text{Aliquot of the digest taken} \times \text{Weight of the sample taken} \times 1000}$$

3.9.10 Determination of Protein content

Protein content can be measured by estimating the nitrogen content of the material and then multiplying the nitrogen value by 6.25 because the conversion factor of nitrogen to protein is 6.25. This is referred to as crude protein content, since the non-protein (NPN) present in the materials was taken into consideration in the present investigation. Protein content was calculated as follow:

$$\text{Protein}\,\% = \text{Nitrogen}\,\% \times 6.25$$

3.9.11 Determination of Oil Content

Crude fat content was determined in the laboratory of Bangladesh Agricultural Research Institute (BARI) by following method of AOAC (1990).

Working Procedure

Fully matured siliquae were collected and their seeds were separated; next, they were dried in an oven at 105°C for 1 hr. The dried seeds of 50 g per sub plot were taken in mortar and ground into fine particles of 0.1 mm. Then 3 g of powder was transferred to a thimble and plugged the top of the thimble with a wad of fat-free cotton. The thimble was dropped into the fat extraction tube of Soxhlet apparatus. The bottom of the extraction tube was attached to a Soxhlet flask. Approximately 100 ml of anhydrous petroleum ether was poured through the powder sample into the receiving flask. Then top of the fat extraction tube was attached to the condenser. The sample was extracted for 16 hr or longer on a water bath. The water bath was regulated so that the ether could volatilize, condense and drop continuously upon the sample without any appreciable loss.

At the end of extraction period, the thimble was removed from the apparatus and most of the ether was distilled off by allowing it to collect in the Soxhlet tube. The ether was poured off when the tube was nearly full. When the ether had reached a small volume, it was poured into a small, dry, (previously weighed) beaker through a small funnel containing a plug of cotton. The flask was rinsed using a small portion of ether. The ether was then evaporated on a heater

at low heat. It was dried, cooled and weighed. The difference in the weights gave the ether-soluble material present in the sample.

Calculation

$$\text{Oil content (\%)} = \frac{\text{Weight of ether soluble material}}{\text{Weight of the sample taken}} \times 100$$

3.9.12 Determination of Boron

Boron content was measured using spectrophotometry method (Azomethine) described by Harp (1997).

Sample preparation

Three gram of sample was weighed in crucibles. Samples were dried for 12 h at 75°C in oven and the dry samples were kept in furnace for 3 h at 525°C until ashed. Ashes were extracted with 10 mL of 2M HNO_3 and were heated on a hot plate. After dissolution, the contents were filtered by filter paper and diluted to a final volume of 50 mL with distilled water. This final solution was used for analysis.

Spectrophotometry

The method used for the spectrophotometric determination of micro amounts of Boron is based on the Boron-catalyzed condensation of salicylaldehyde with HCl. Under the optimum conditions, the wavelength of maximum absorption of the yellow complex was found as 412 nm.

3.9.13 Determination of Sulphur

Sulphur concentration was measured according to Pearson (1976).

Sample preparation

1g sample with 15ml of diacid mixture (2:1) (HNO_3: $HClO_4$) was taken in a beaker and boiled until the solution become clear. Cooled and made the volume in 100 ml.

Working procedure

$MgSO_4.7H_2O$ Solution (For 100 ppm Sulphur)

Exactly 0.769g $MgSO_4.7H_2O$ was taken in a 1000ml volumetric flask and added 200ml distilled water. Shaken well to dissolve. Then made the volume up to the mark with distilled water. Concentration of that solution is made 100ppm of Sulphur.

Series solution of Sulphur

0 ml, 0.2 ml, 0.5 ml, 1.0 ml, 2.0ml, 4.0 ml and 6.0 ml of 100 ppm S solution was taken in several 100 ml volumetric flask and made volume upto 20 ml with distilled water. For unknown sample a blank solution was made which contained 20 ml distilled water.

Spectrophotometry

Each standard and unknown solution was taken in a 150 ml conical flask. In each conical flask 0.3 g Barium chloride, waited for 30 minutes and reading was taken in a spectrophotometer at 425 nm wavelength.

3.9.14 Determination of phosphorus

Phosphorous concentration was measured by the method of Pearson (1976) with a slight modification given below:

Sample preparation

1 gm sample with 15 ml of diacid mixture (2:1) (HNO_3: $HClO_4$) was taken in a beaker and boiled until the solution become clear. Cooled and made the volume in 100 ml.

Working procedure

KH_2PO_4 (50 ppm Phosphorus)

Exactly 0.2195 g dried KH_2PO_4 was taken in a 1000ml volumetric flask and added 200ml distilled water. Then 4.86 ml conc. H_2SO_4 was added and shaken well to dissolve. Finally made the volume up to the mark with distilled water.

Stannous Chloride solution

5 g Stannous Chloride solution was taken in a 150 ml beaker and 10 ml HCl was added. Then heat was applied to dissolve the solution and finally made the volume 100 ml in a100 ml volumetric flask.

Sulphomolybdic acid solution

a. Exactly 25 g ammonium heptamolybdate was taken in 500 ml beaker and about 200 ml distilled water added. Warmed at 60^0 C until the solution become clear then cooled it.
b. 500 ml distilled water was taken in a 1000 ml beaker. 275 ml conc. H_2SO_4 was added slowly and cooled.

Sample a and sample b was added. Ammonium heptamolybdate solution was transferred in a 1000 ml volumetric flask. 200 ml H_2SO_4 solution was added slowly and made volume upto the mark with distilled water. Now it is called Sulphomolybdic acid solution.

Series solution of Phosphorus

2.5 ml, 5 ml, 10 ml, 15 ml, 20ml, 25 ml and 30 ml of 2 ppm P solution was taken in several 500 ml volumetric flask and made volume upto 20 ml to 500 ml with distilled water. For unknown sample a blank solution was made which contained 5 ml of 2 ppm solution.

Spectrophotometry

Each standard and unknown solution was taken in several 100 ml volumetric flask. 20 ml distilled water and 4 ml sulphomolybdic acid was added. 5-6 drops stannous chloride was added and made volume upto the mark with distilled water. Then absorbance reading is taken in a spectrophotometer at 660 nm wavelength within 3-4 minutes.

3.9.15 Determination of potassium

Potassium content was measured using the method of Pearson (1976) with slight modification as follow:

Sample preparation

1 gm sample with 15 ml of diacid mixture (2:1) (HNO_3: $HClO_4$) was taken in a beaker and boiled until the solution become clear. Cooled and made the volume in 100 ml.

Working procedure

Preparation of 100 ppm solution

Exactly 1.907g KCl was taken in a 1000ml volumetric flask and added 300-400 ml distilled water. Shaken well to dissolve completely. Then made the volume up to the mark with distilled water. Diluted 50 ml to 500 ml solution. Concentration of that solution is made 100 ppm of potassium.

Series solution of K

5ml, 10ml, 15ml, 20ml, 25ml, 30ml, 40ml, 50ml and 60ml of 100ppm K solution was taken in several 100 ml volumetric flask and made volume up to the mark with distilled water. Finally in Flame Emission Photometer showed the reading directly for unknown solution. Final result got in ppm.

3.10 Statistical analysis

The collected data were analyzed statistically using "Analysis of Variance" with MSTATC computer programme and the difference among treatment means were adjusted by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

This study was conducted to know the effect of combined of Sulphur and Boron on yield and yield contributing characters of mustard as well as the nutrient content and their uptake by plants and seeds. The analyses of variance (ANOVA) of the data on different components are given in Appendices. The results have been presented and discussed, and possible explanations have been given under the following headings:

4.1 Yield and yield contributing character of mustard

Yield contributing characters such as plant height, branches per plant, pod length, capsule per plant, seed per capsule, 1000 seed weight, grain yield, stover yield and harvesting index were recorded in every plot of the trial.

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4.1.1 Combined effect of Sulphur and Boron level on plant height

Combined effect of Sulphur and Boron level on mustard plant height is shown in Figure 1. Mustard plant height was significantly ($p<0.05$) differed because of the combined of Sulphur and Boron (Appendix I). The highest plant height (166.3 cm) was resulted from the treatment of S2B3 (20 kg S ha^{-1} and 3 kg B ha^{-1}), whereas lowest height (125 cm) was found for S0B1 (0 kg S ha^{-1} and 1 kg B ha^{-1}) treatment (Figure 1).

Plant height observed in this study was higher than the results observed by Mohiuddin (2007) who reported the tallest mustard plant (93.0cm) from the treatment combination N2S3 comprising of 80 kg N/ha + 24 kg S/ha, while the shortest plant (72.0cm) was recorded from N0S0 i.e. no nitrogen no Sulphur. On the other hand, Islam (2003) reported the highest plant height (74.23cm) from the treatment of 30kg S + 20kg Mg ha^{-1}, whereas lowest height (56.67cm) was obtained from control treatment.

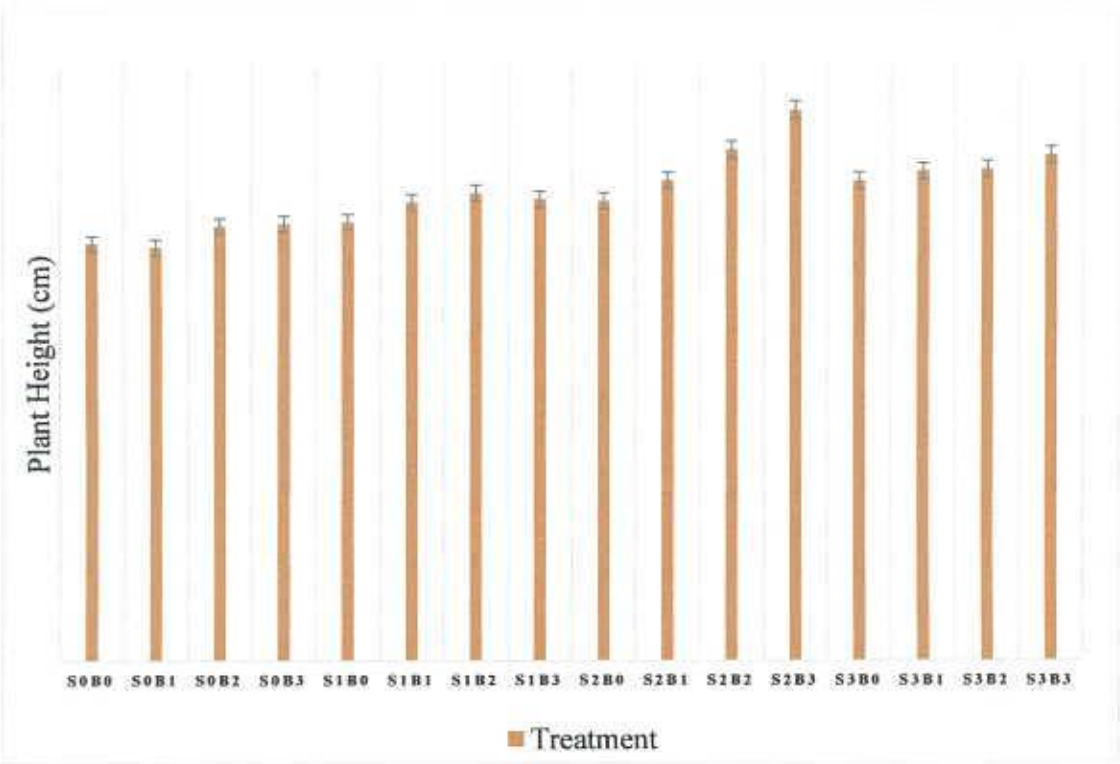

Figure 1: Combined effect of Sulphur and Boron on plant height; S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.1.2 Combined effect of Sulphur and Boron level on the number of branches/plant

Combined of Sulphur and Boron significantly affected the number of branches/plant (Appendix II). Number of brunches/plant increased with the different levels of Sulphur and Boron (Figure 2). However, highest and lowest number of brunches were resulted 5.25 and 4.08 for combination treatment S2B3 (20 kg S ha^{-1} and 3 kg B ha^{-1}) and control (0 kg S ha^{-1} and 0 kg B ha^{-1}) respectively.

In a previous study, Mohiuddin (2007) reported significant combined effect between nitrogen and Sulphur for the number of branches per plant. He reported the maximum number of branches per plant (8.10) was observed from the treatment combination N2S3 having 80 kg N/ha + 24 kg S/ha.

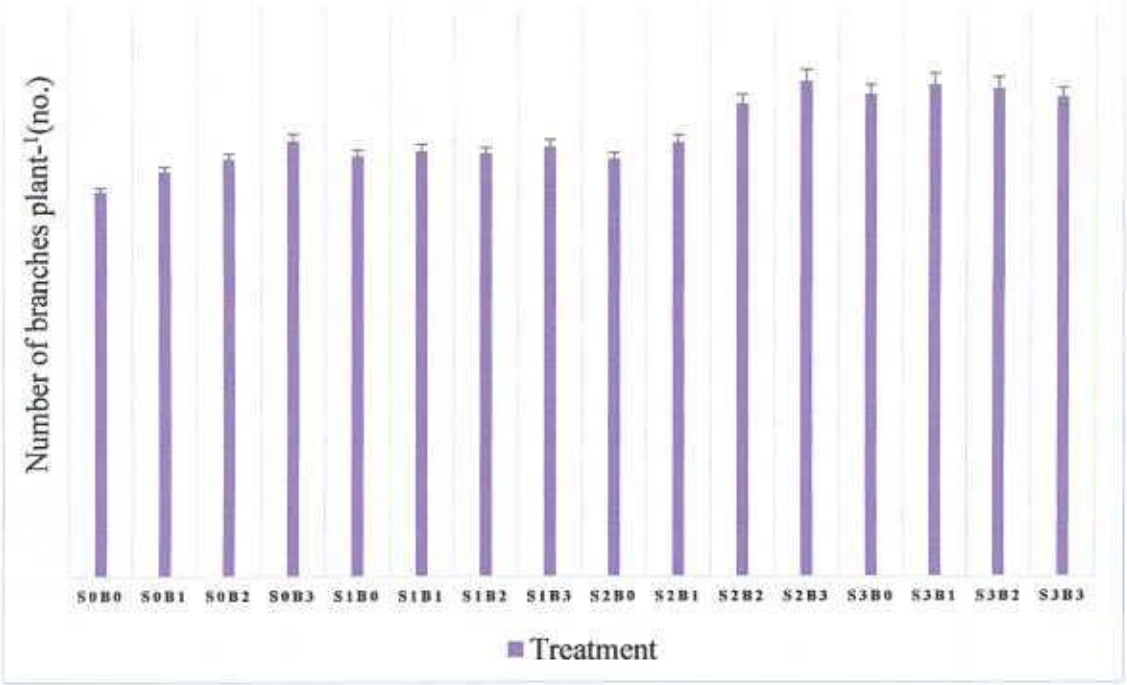

Figure 2: Combined effect of Sulphur and Boron on number of branches $plant^{-1}$;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.1.3 Combined effect of Sulphur and Boron level on pod length

Variations in pod length for different levels of Sulphur and Boron are shown in Figure 3. Results revealed that increased amount of Sulphur and Boron significantly ($p<0.05$) influenced the pod length in this research (Appendix III). Pod length varied from 3.66 cm to 4.2 cm for different combineds of selected fertilizers (Figure 3). Highest pod length (4.2cm) was recorded from S2B2 comprising of 20 kg S ha^{-1} and 2 kg B ha^{-1}, which was statistically similar to next treatments applied in this research. Lowest pod length (3.66cn) was found in control. From this finding, it could be suggested that 20 kg S ha^{-1} and 2 kg B ha^{-1} is optimum combined for maximum pod length. In a previous study, Huq (2012) observed positive effect of combined of Sulphur and Boron on the capsule length of sesame.

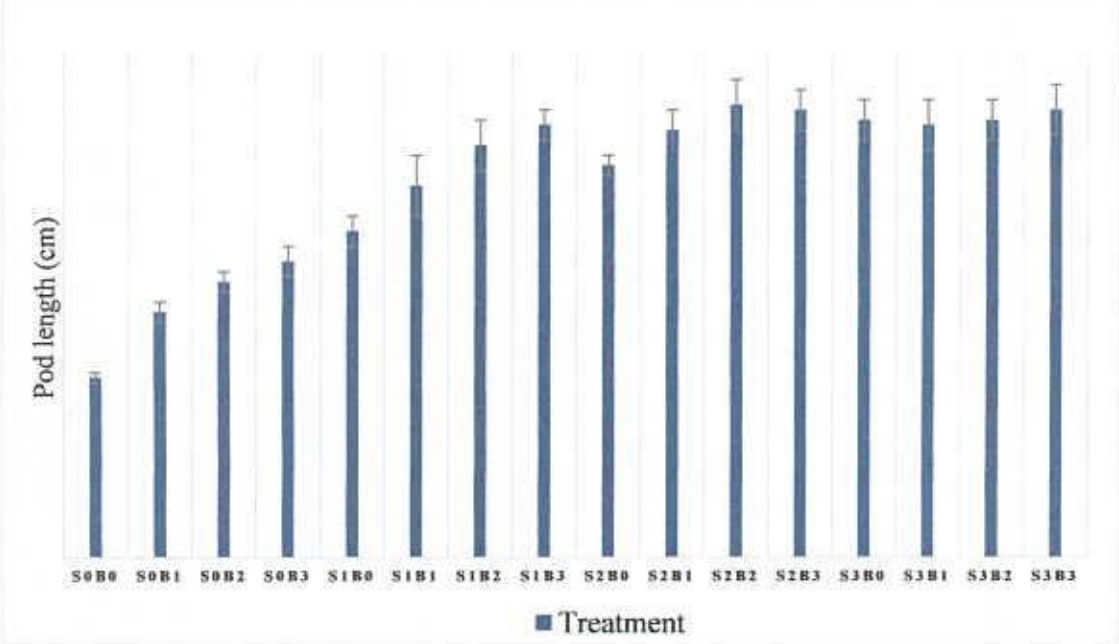

Figure 3: Combined effect of Sulphur and Boron on pod length; S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

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4.1.4 Combined effect of Sulphur and Boron capsule/plant

Number of capsule on a plant significantly ($p<0.05$) influenced by the combination of Sulphur and Boron (Appendix IV). Lowest number of capsule (228 no) was observed for combination of S0B0 (0 kg S ha^{-1} and 0 kg B ha^{-1}), whereas highest number of capsule (241.3 no) was resulted for S2B3 (20 kg S ha^{-1} and 3 kg B ha^{-1}). Figure 4 also shows that capsule number/plant was largely influenced by born application than Sulphur when separately applied over control.

Similar trend regarding capsule formation/plant was observed by Gupta *et al.* (1980) who reported that application of Boron increased siliqua formation of mustard.A significant combined effect between nitrogen and Sulphur for number of siliqua per plant was also observed by Mohiuddin (2007). The maximum number of siliqua per plant (165) was recorded from the treatment combination N2S3 (80 kg N/ha + 24 kg S/ha).

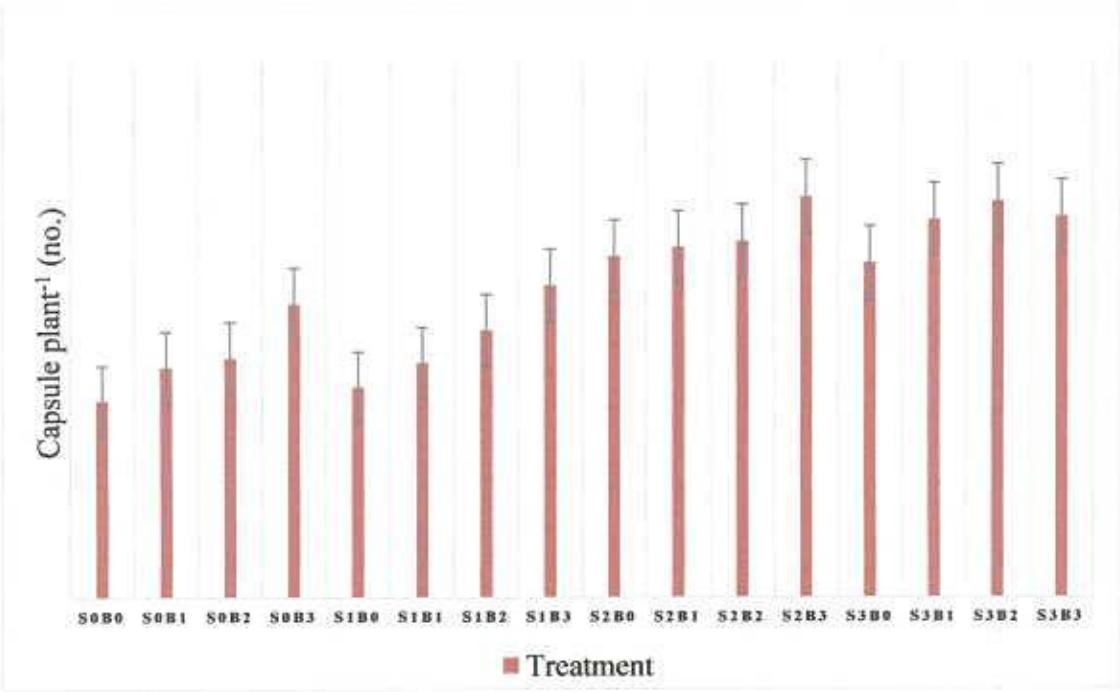

Figure 4: Combined effect of Sulphur and Boron on capsule $plant^{-1}$; S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.1.5 Combined effect of Sulphur and Boron on number of seed/capsule

The combined effect of Sulphur and Boron on number of seed/capsule was found significant ($p<0.05$). Number of seed/capsule (15.9) was highest with the combination of S2B2 (20 kg S ha^{-1} and 2 kg B ha^{-1}) but statistically not differed from second highest result (15.75 no) for S2B3 (20 kg S ha^{-1} and 3 kg B ha^{-1}) treatment (Appendix V). Lowest seed/capsule (9.29) was found with the control (Figure 5). From the combined effect it was found that only combination of Sulphur and born increased the number of seed/capsule significantly. In addition, impact of Sulphur level was more pronounced than Boron level on higher seed yield/capsule (Figure 5). This result regarding effect of Sulphur on seed yield/capsule was supported by the result of Singh *et al.* (2007).

Number of seed per capsule in this study was quite lower than the value (24.7no) reported by Mohiuddin, (2007) for the treatment combination N2S3 comprising of 80 kg N/ha + 24 kg S/ha. On the other hand, Islam (2003) reported the highest seeds per pod (17.6nos) from the treatment of 30kg S + 20kg Mg ha^{-1}, whereas lowest height (12.42nos) was found in control.

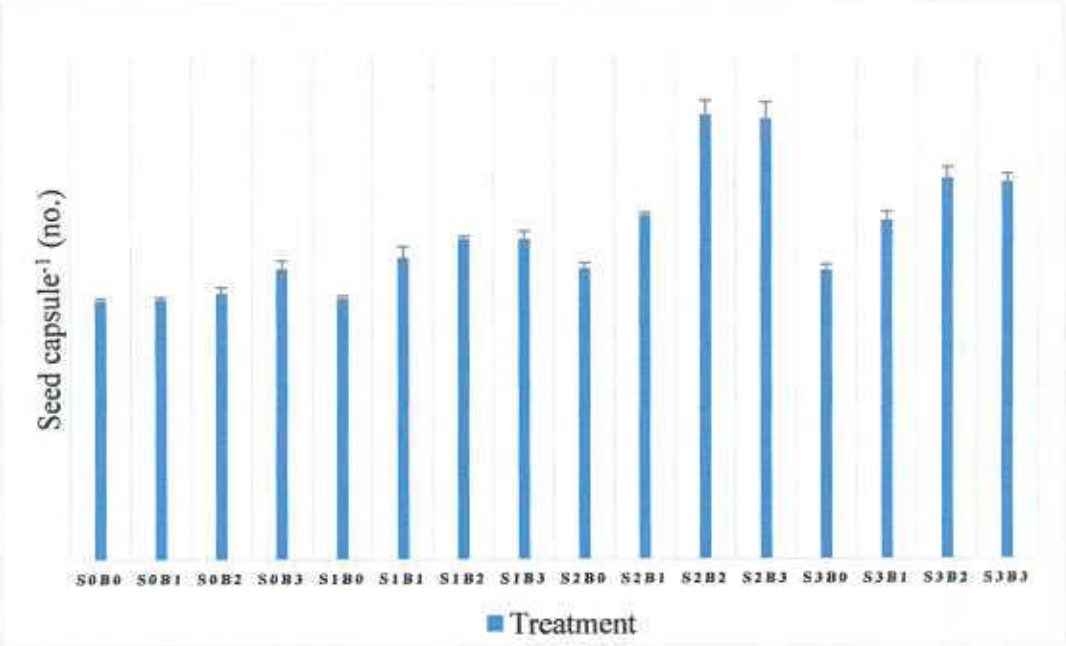

Figure 5: Combined effect of Sulphur and Boron on seed capsule^{-1};S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.1.6 Combined effect of Sulphur and Boron level on seed weight

The results indicated that the weight of 1000 no seed increased from 8 g in control to 15.4 g with S2B3 treatment. It was also observed that the increasing level of Boron and Sulphur separately influenced the seed weight. But combined effect was found significant ($p<0.05$) in this research. This result was similar to the result observed by Karthikeyan and Shukla (2011) who reported highest dry matter of mustard seed with the combination of S60B2 (60 g S kg^{-1} and 2 mg B kg^{-1}).

This finding was higher than the result reported by (Mohiuddin, 2007) who observed the highest weight of 1000 seed (2.86g) from the treatment combination N2S3 comprising of 80 kg N/ha + 24 kg S/ha and the lowest (1.60g) was recorded from N0S0 where no nitrogen and Sulphur were applied. At previous study, Islam (2003) reported the highest 1000-seed weight (2.75g) from the treatment of 30kg S + 20kg Mg ha^{-1}, whereas lowest 1000-seed weight (1.57g) was obtained from the treatment of 45kg S + 30kg Mg ha^{-1}.

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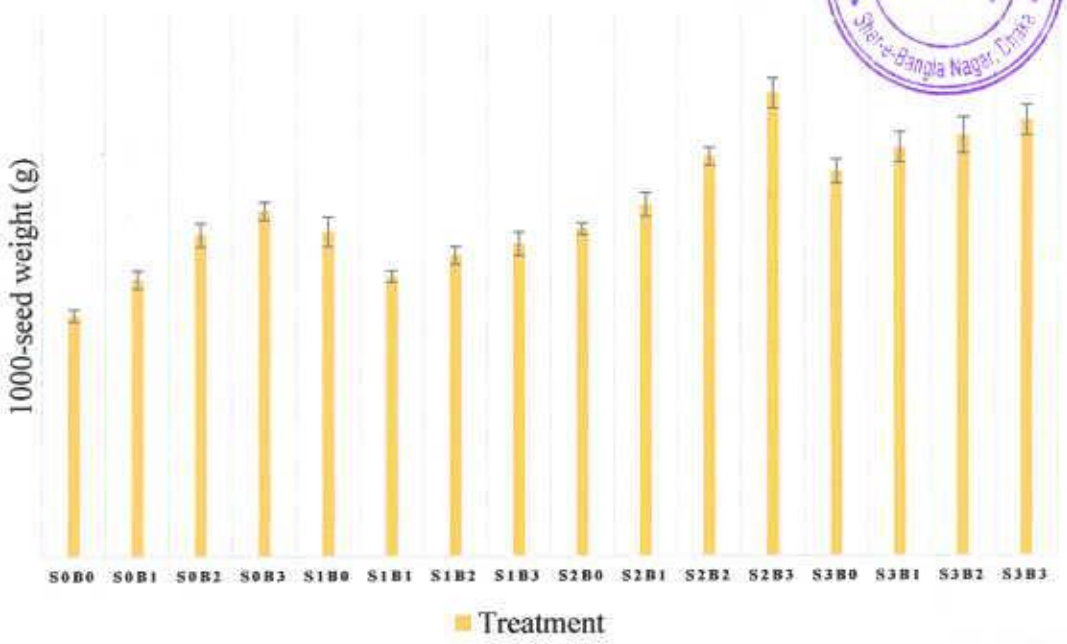

Figure 6: Combined effect of Sulphur and Boron on seed weight; S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.1.7 Combined effect of Sulphur and Boron on grain yield

Significant difference was observed among combined treatments of Sulphur and Boron in respect of grain yield at 5% level of probability (Appendix VII). Increasing rate of grain yield was not same with all combined treatments of higher Sulphur and Boron level. The highest grain yield (2180 kg ha^{-1}) was obtained from S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}) and lowest result (1806 kg ha^{-1}) was found with control (Figure 7). Karthikeyan and Shukla reported increased mustard seed yield with the combination of higher sulfur and Boron level and highest yield (20.6 g pot^{-1}) with S60B2 (60 g S kg^{-1} and 2 mg B kg^{-1}) treatment.

Lower grain yield of mustard was revealed by Mohiuddin (2007) who found the highest yield (1738 kg/ha) from the treatment combination N2S3 comprising of 80 kg N/ha + 24 kg S/ha and the lowest (850 kg/ha) from N0S0 where no nitrogen and Sulphur was applied. However, quite lower yield of mustard was also observed by Islam (2003) who reported the highest seed yield (984.00 $kgha^{-1}$) from the treatment of 30kg S + 20kg Mg ha^{-1}, whereas lowest seed yield (517.33 $kgha^{-1}$) was obtained from the control.

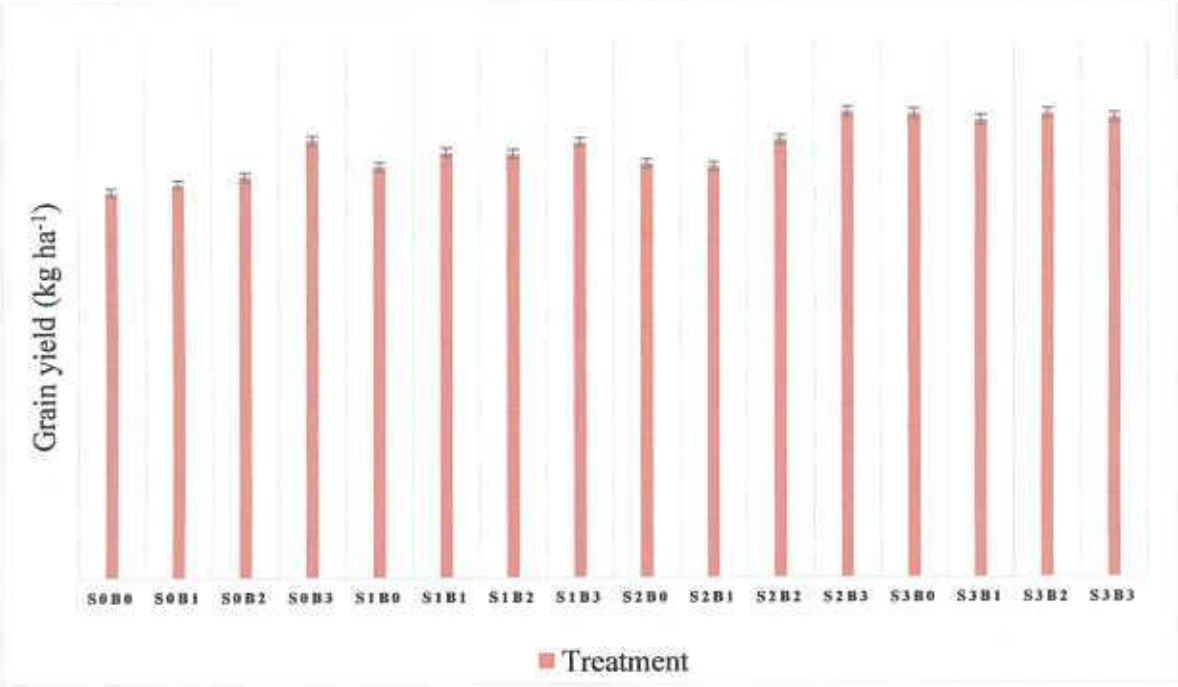

Figure 7: Combined effect of Sulphur and Boron on grain yield; S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.1.8 Combined effect of Sulphur and Boron on stover yield

Figure 8 indicates that stover yield increased from 2776 kg ha^{-1} in control to 2800 kg ha^{-1} with treatment of Sulphur 30 kg ha^{-1} and Boron 1 kg ha^{-1}. However, combine effect of Sulphur and Boron on stover yield was found significant ($p<0.05$) in this research (Appendix VIII). Results also revealed that the impact of Sulphur on stover yield was more than the Boron level.

Stover yield in this study was much higher than the result of Mohiuddin (2007) who reported the highest shoot yield (1748/ha) from the treatment combination N2S3 comprising of 80 kg N/ha + 24 kg S/ha and the lowest (918 kg/ha) from N0S0 where no nitrogen and Sulphur was applied. This variation may be occurred due to harvesting method of mustard.

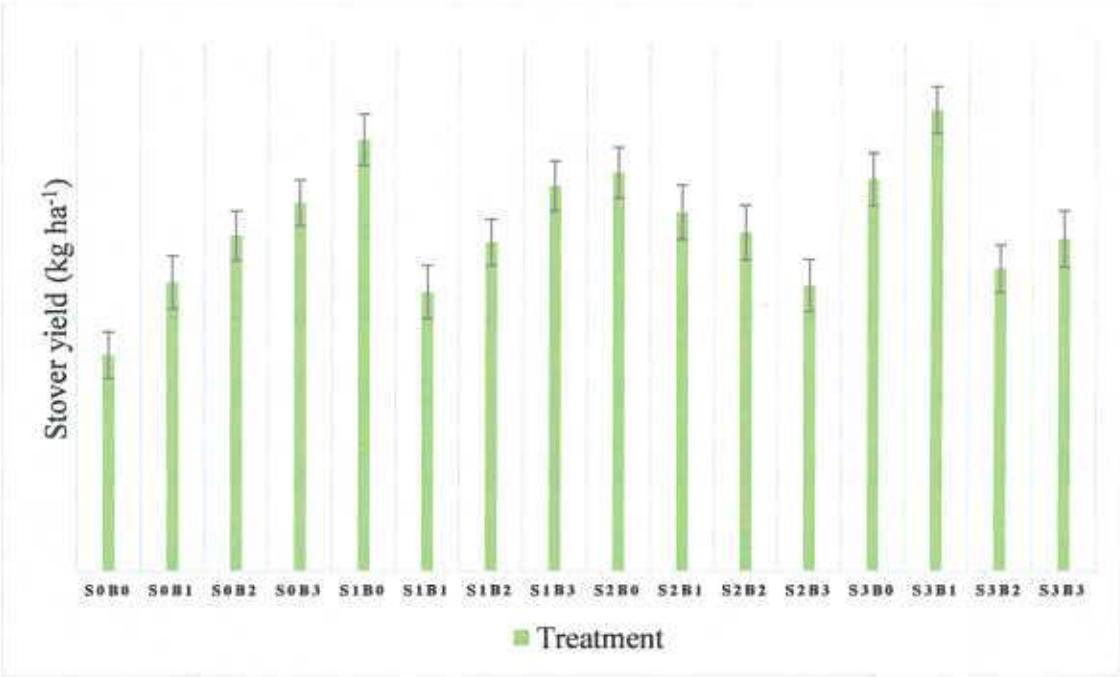

Figure 8: Combined effect of Sulphur and Boron on Stover yield;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.1.9 Combined effect of Sulphur and Boron on harvesting index

Harvesting index was positively influenced as a combined effect of different levels of Sulphur and Boron (Figure 9). Significant ($p<0.05$) effect of combined dose of Sulphur and Boron on harvesting index was revealed in this research work (Appendix IX). The optimum combined dose of 20 kg ha^{-1} S and 3 kg ha^{-1} B was found regarding highest harvesting yield of mustard in this research (Figure 9). Lowest harvest index (39%) was found from the treatment of S0B1 (0 kg S ha^{-1} and 1 kg B ha^{-1}). If combined dose above the optimum dose is applied, there would be risk of lower harvesting index.

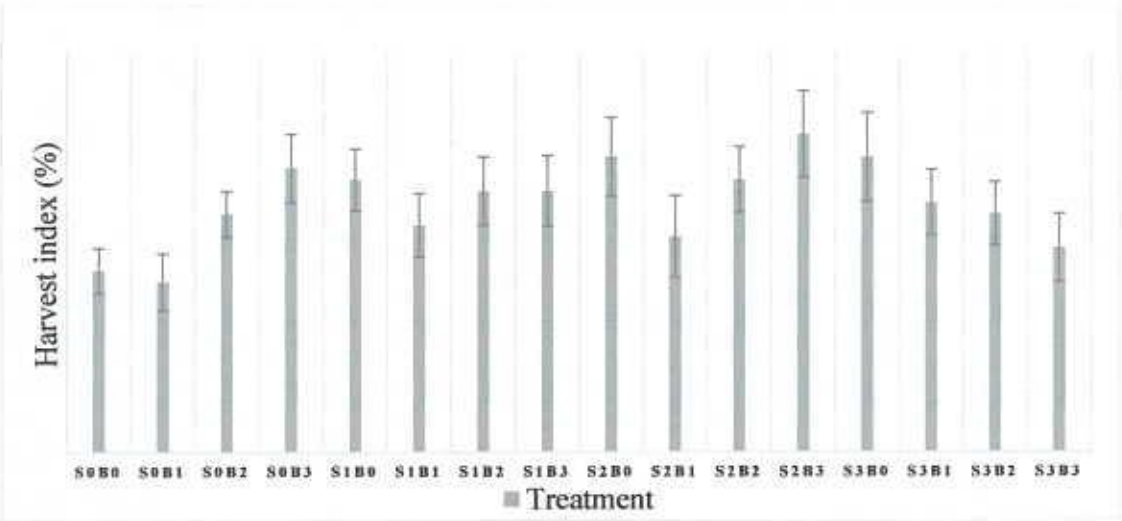

Figure 9: Combined effect of Sulphur and Boron on Harvest index (%);S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.2 Nutrient content in stover and seed

Nutrients such as nitrogen, protein, oil, Sulphur, phosphorus, potassium, Sulphur and Boron content in stover and seed were estimated for different combinations of Sulphur and Boron.

4.2.1 Combined effect of Sulphur and Boron on nitrogen content

Significant diffrence in nitrogen content in stover was found among the treatments (Appendix X). A range of nitrogen content (1.2% to 1.51%) was observed in stover (Figure 10). Lowest nitrogen content in stover was found in control and highest was resulted with S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}). Marginal difference in nitrogen content in stover was resulted in treatments of S2B2, S2B3, S3B1, S3B2 and S3B3 (Appendix X).

On the other hand, lowest nitrogen content (3.41%) in seed was observed in control and highest (3.69%) was observed in both of S2B3 (20 kg S ha^{-1} and 3 kg B ha^{-1}) and S3B3 (30 kg S ha^{-1} and 3 kg B ha^{-1}) treatments (Figure 10). Significant diffrences were observed among the treatments with respect to nitrogen content in seed (Appendix X). Though difference among S2B3, S3B2 and S3B3 treatments was marginal.

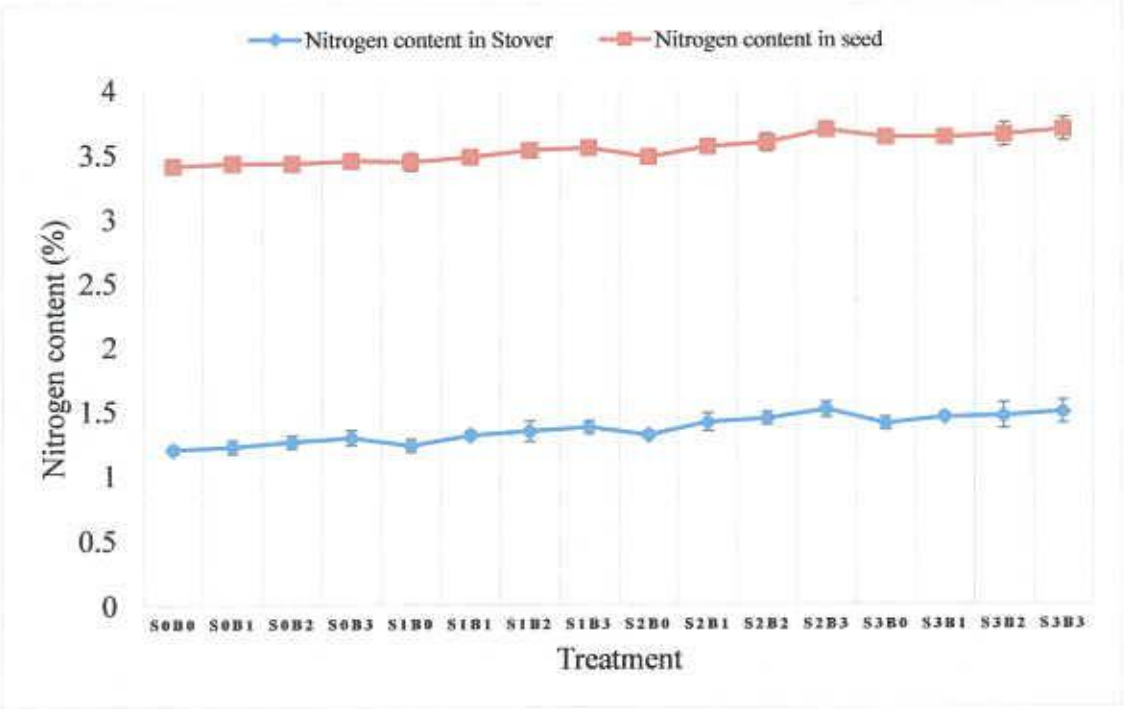

Figure 10: Combined effect of Sulphur and Boron on nitrogen content;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.2.2 Combined effect of Sulphur and Boron on protein content

Protein content in stover was significantly affected by the combined of Sulphur and Boron (Appendix X). Highest protein content (9.44%) was found as an effect of S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}), whereas lowest value (7.50%) was observed in control.

Positive effect of the combined of Sulphur and Boron in protein content of seed was also found in this study (Figure 11). S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}) resulted highest protein content (23.06%) followed by S2B0 and S2B1 treatment. On the other hand, control sample was found with least protein content.

This result was confirmed that of Brady (1996) who reported that protein synthesis is affected by Boron level. In earlier study, Havlin *et al.* (1999) reported that Sulphur had significant influence on protein content in oil seeds because S-containing amino acids including cystine, cysteine and methionine are synthesised largely by Sulphur apllication. Similar finding was also reported by Tomar *et al.* (1996) who found increased amount of protein with the increase in Sulphure rate.

Intercation effcet on protein content in mustard was accrdence with the results of Verma *et al.* (2002) who recorded significantly higher protein yield in combination of S 60 $kgha^{-1}$ + B 1.0 $kgha^{-1}$followed by S 40 $kgha^{-1}$ + B 1.0 $kgha^{-1}$. In contrust, Sarker *et al.* (2002) reported that there was no significant effcet of the intercation of Boron and Sulphur in oil content of soybean-4. ;

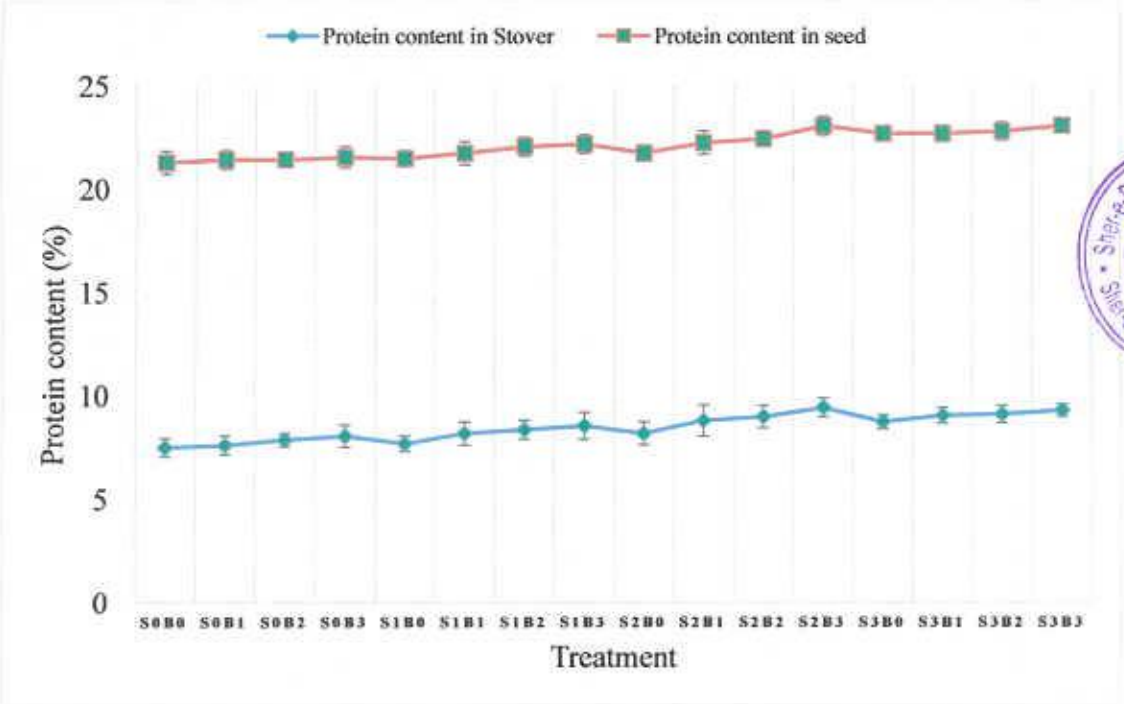

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Figure 11: Combined effect of Sulphur and Boron on protein content;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.2.3 Combined effect of Sulphur and Boron on oil content in seed

Positive effect of the combined of Sulphur and Boron on oil content was revealed (Figure 12). Oil content gradually incraesed with the increasing of combination of Sulphur and Boron. However, there was no significant difference amoung oil contents as effcet of increased Boron level with same amount of Sulphur (Appendix X).Highest oil content (45.01%) was recorded for S3B3 treatment (30 kg S ha^{-1} and 3 kg B ha^{-1}) and lowest amount (41.67%) was recorded for control. This finidng was supported by Havlin *et al.* (1999) and Babhulkar *et al.*(2000) who reported that Sulphur had significant influence on oil content of oil seeds because Sulphur helped to synthesis fatty acids.

The findings of this study partiallay supported by Sarker *et al.* (2002) who reported that Boron application did not influenced the oil content significantly and intercation of Boron and Sulphur failed to show significant difference in oil content of soybean-4. In contrast, Khatik *et al.* (1992) observed that Sulphur appliaction decreased the oil content. On the other hand, Malewar *et al.* (2001) and Noor *et al.* (1997) reported that oil is synthesised by Boron nutrient.

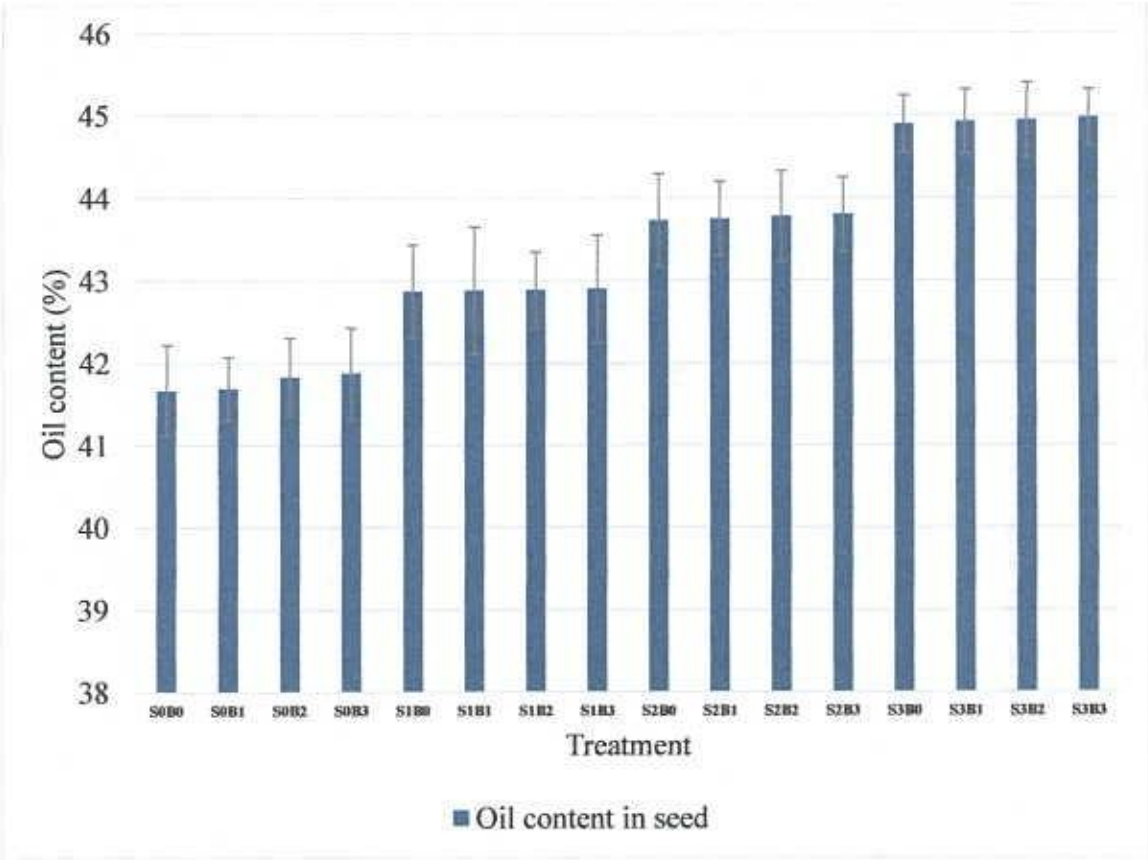

Figure 12: Combined effect of Sulphur and Boron on oil content;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.2.4 Combined effect of Sulphur and Boron on phosphorous content

Combined effect of Sulphur and Boron on phosphorous content in stover and seed was positive (Figure 13). Highest amount of phosphorous in stover and seed was recorded by the treatment of S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}) and lowest value in both of stover and seed was recorded for control. Significant difference in phosphorous contents as effect of S2B2, S2B3, S3B0, S3B1, S3B2 and S3B3 treatment was not observed in both of stover and seed (Appendix X).

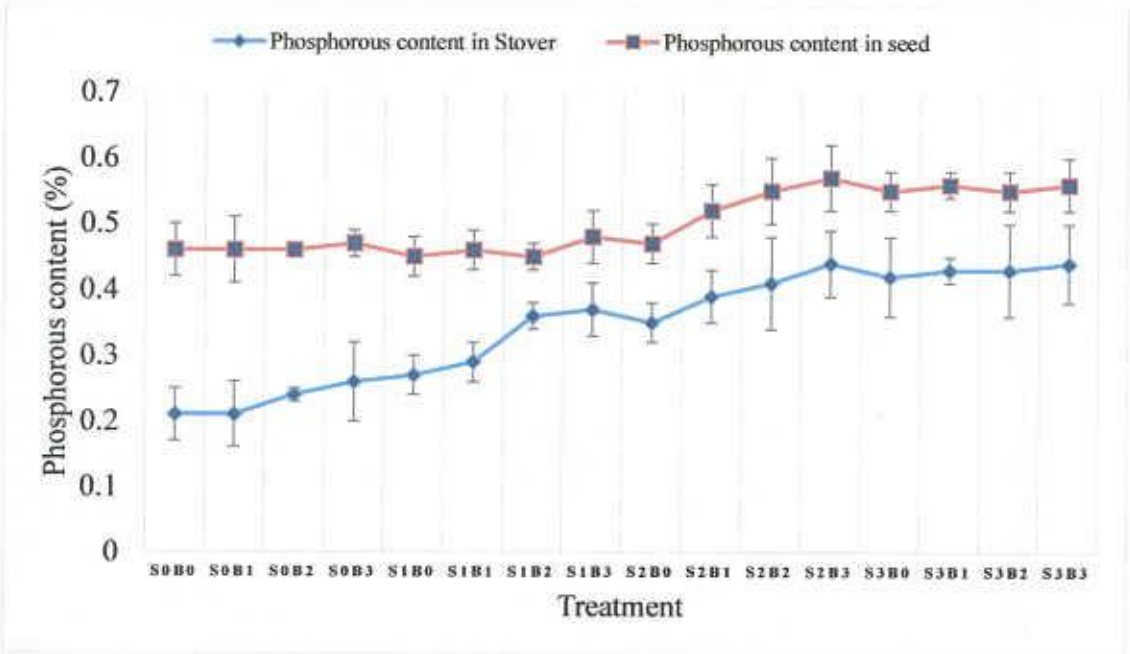

Figure 13: Combined effect of Sulphur and Boron on phosphorous content;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.2.5 Combined effect of Sulphur and Boron on potassium content

The combined effect of Sulphur and Boron on potassium content was significant (Appendix X). potassium content in both stover and seed gradually increased as combined effect of increasing amount of Sulphur and Boron (Figure 14). Highest potassium content in both of stover (2.68%) and seed (1.38%) was resulted for S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}), whereas lowest amount was observed in control samples in both cases. However, significant difference in potassium ocntent was only observed as combined effect up to S2B3 treatment (Appendix X).

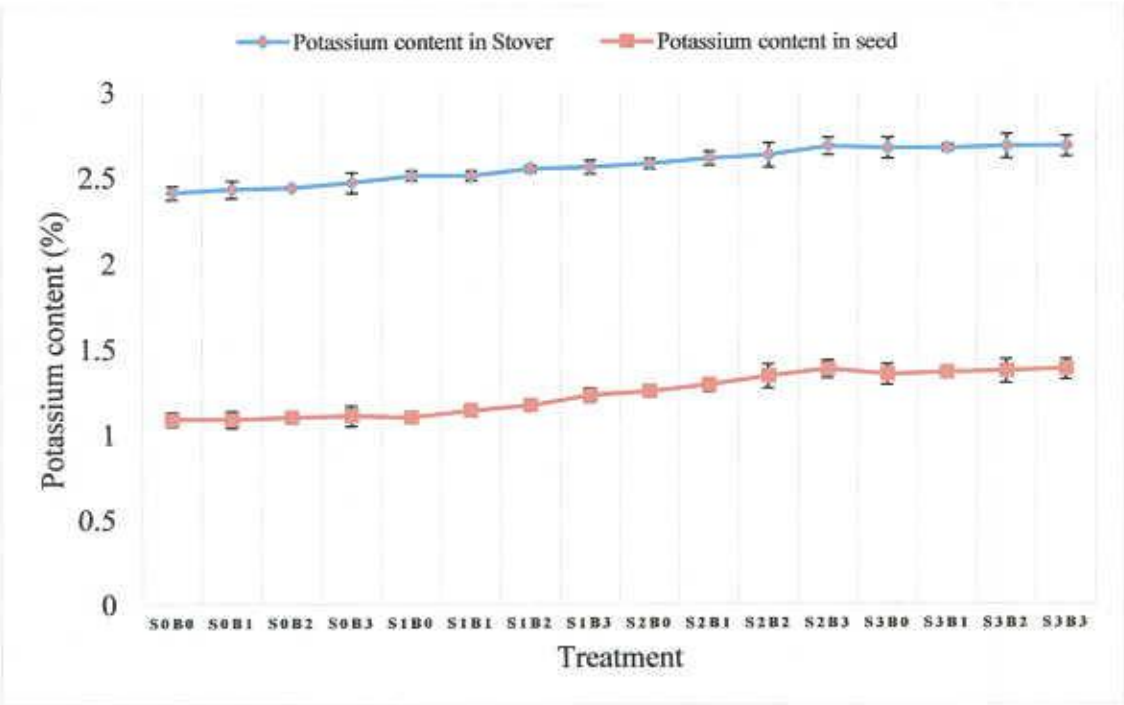

Figure 14: Combined effect of Sulphur and Boron on potassium content;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.2.6 Combined effect of Sulphur and Boron on Sulphur content

Sulphur content in both of stover and mustard seed significatly affected by both of Sulphur and Boron (Appendix X). Figure 15 shows that incresing amount of Sulphur largely affcted the Sulphur content in stover and seed with the combination of incresaing amount of Boron. Maximum Sulphur content 0.38% and 0.79% were resulted in stover and seed repectivily for S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}). In both cases, lowest amount of Sulphur was resulted in control sample. Furthermore, it could be reported that Sulphur uptake was not statistically affected at same level of S with the incraesed of Boron. A similar result was reported by Karthikeyan and Shukla (2011) who observed that at the same level of S, the water soluble S decreased with increasing levels of Boron, which may be due to the increased requirement of Sulphur by plants.

Karthikeyan and Shukla (2008) also found that combined effect of Boron and Sulphur on the S uptake was statistically significant for sunflower and mustard seed, but maximum Sulphur uptake in straw was found in S60Bl level. Ganesharmurthy (1996) and Chand *et al.* (1997) found that Sulphur application increaesd the Sulphur uptake in mustard. Partial similar result was observed by Sarker *et al.* (2002) who reported that Sulphur dose positively affected it's uptake but there is no significant effcet of combined of Sulphur and Boron on Sulphur uptake in Soybean-4. But Krishna (1995) found a contradictory result that Sulphur uptake decreased with it's increased application.

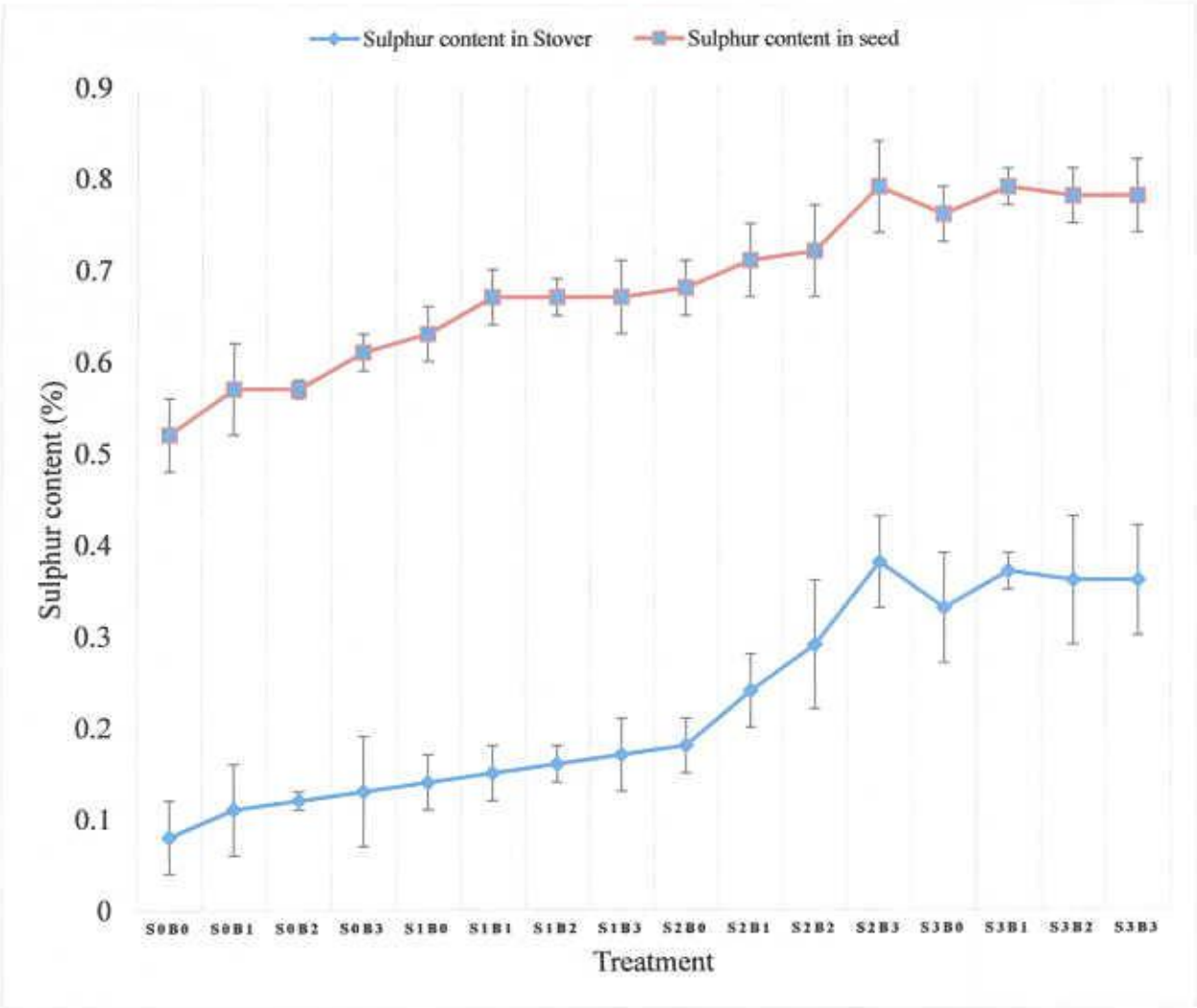

Figure 15: Combined effect of Sulphur and Boron on Sulphur content;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

4.2.7 Combined effect of Sulphur and Boron on Boron content

Combined effect of Sulphur and Boron on Boron content in stover and seed is presented in Figure 16. Boron content in both of stover and seed increased significantly due to different combined treatments (Appendix X). Maximum Boron content in both of samples was observed for S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}) and lowest was resulted in control. A range of Boron content (42.11ppm to 46.89ppm) was observed in stover, whereas Boron content ranged from 67.67ppm to 59.89ppm in mustard seed. It was also observed that Boron content increased with the incresing of Boron level as combined with high amount of Sulphur.

This finding was inline with the results of Karthikeyan and Shukla (2011) who observed increasd amount of readily soluble born in mustard (0.97%) for combined treatment of S60B3 (60mg/kg S and 3mg/kg B) compared to control (0.17%). Karthikeyan and Shukla (2008) also reported that low amount of Boron in soil is major cause of response to added Boron. On the other hand, Sarker *et al.* (2002) observed that highest Boron uptake in soybean-4 was resulted by the application of Boron 4kg/ha. They also observed that Boron uptake in soybean-4 was not significantly affected by the treatemnt combination of Sulphur and Boron.

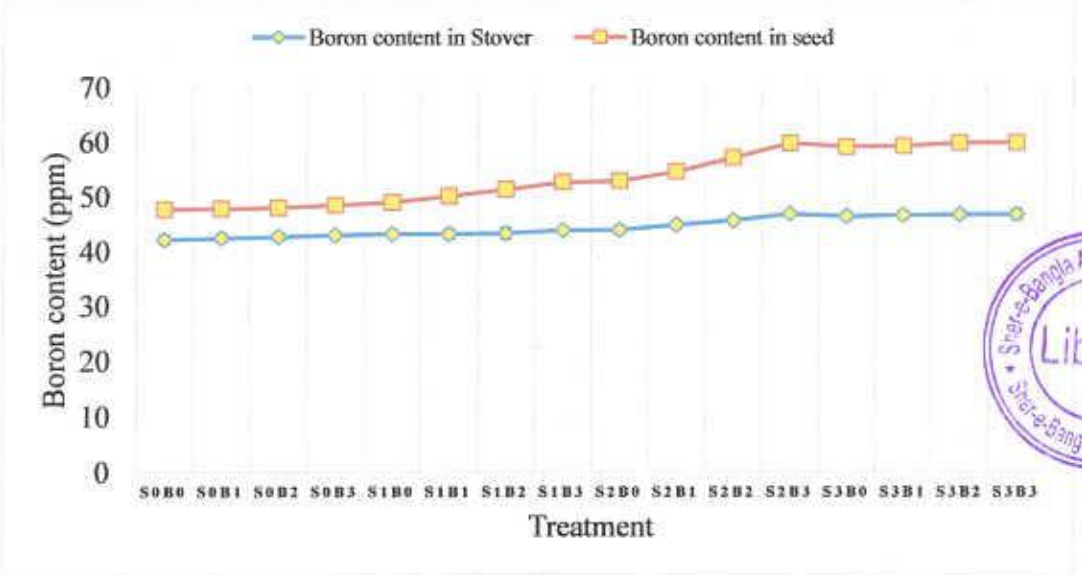

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Figure 16: Combined effect of Sulphur and Boron on Boron content;S_0 (0 kg ha^{-1}), S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}), S_3 (30 kg ha^{-1}); B_0 (0 kg ha^{-1}), B_1 (1 kg ha^{-1}), B_2 (2 kg ha^{-1}), B_3 (3 kg ha^{-1})

CHAPTER V

SUMMARY AND CONCLUSION

Results revealed that main effect of Sulphur and Boron was significant in respect of studied parameters viz. plant height, number of branches plant^{-1}, pod length, capsule plant^{-1}, seed capsule^{-1}, 1000 seed weight, grain yield, stover yield, harvest index, oil content in mustard and N, protein, K, P, S, B content in stover and seed.

It was revealed that the combined effect of Sulphur and Boron was also remained significant. Combined of Sulphur and Boron S2B3 (20 kg S ha^{-1} and 3 kg B ha^{-1}) resulted the height plant height (166.3 cm), number of branches plant^{-1} (5.25 no), pod length (4.2 cm), capsule plant^{-1} (241.3 no),seed capsule^{-1} (15.75 no),1000-seed weight (15.4 g), grain yield (2180 kg ha^{-1}) and harvest index (40.3%). Stover yield (2747 kg ha^{-1}) was resulted for S2B3 treatment where highest (2800 kg ha^{-1}) one was for S3B1 (30 kg S ha^{-1} and 1 kg B ha^{-1}).

On the other hand, highest amount of N (1.51% and 3.69%), protein (9.44% and 23.06%), P (0.41% and 0.55%), K (2.68% and 1.38%), S (0.38% and 0.79%), B (46.89 ppm and 59.89 ppm) were observed in stover and seed respectively as combined effect of S2B3 (20 kg S ha^{-1} and 3 kg B ha^{-1}). Only highest oil content (45.01%) in mustard was recorded for S3B3 treatment (30 kg S ha^{-1} and 3 kg B ha^{-1}), which was statistically identical from the result (43.80%) found for S2B3 treatment (20 kg S ha^{-1} and 3 kg B ha^{-1}).

From the findings of the present study, it may be concluded that Sulphur at the rate of 20 kg ha^{-1}and Boron at the rate of 3 kg ha^{-1} had significant and favorable effect for improving yield component and improving yield of mustard. Considering the results of the present experiment, further studies in the following areas are suggested:

1. Studies of similar nature could be carried out in different agro-ecological zones (AEZ) of Bangladesh for the evaluation of zonal adaptability.
2. Other varieties with different management practice might be included in further studies.

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APPENDICES

Appendix I: Combined effect of Sulphur and Boron level on plant height

Treatment	Plant height (cm)
S0B0	126.1^{g}
S0B1	125.0^{g}
S0B2	131.3^{f}
S0B3	132.1^{ef}
S1B0	132.6^{ef}
S1B1	138.5^{e}
S1B2	141.3^{d}
S1B3	139.4^{e}
S2B0	138.9^{e}
S2B1	145.1^{cd}
S2B2	154.5^{b}
S2B3	166.3^{a}
S3B0	145.1^{cd}
S3B1	147.9^{c}
S3B2	148.7^{c}
S3B3	152.9^{ab}
Level of significance	*

*= Significant at 5% level of probability; Capsule plant-1 within the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

Appendix II: Combined effect of Sulphur and Boron level on the number of branches/plant

Treatment	Number of branches plant^{-1} (no.)
S0B0	4.08^{d}
S0B1	4.29^{c}
S0B2	4.42^{bc}
S0B3	4.61^{b}
S1B0	4.46^{bc}
S1B1	4.51^{b}
S1B2	4.49^{bc}
S1B3	4.56^{b}
S2B0	4.43^{bc}
S2B1	4.6^{b}
S2B2	5.01^{ab}
S2B3	5.25^{a}
S3B0	5.11^{ab}
S3B1	5.21^{a}
S3B2	5.17^{a}
S3B3	5.08^{ab}
Level of significance	*

*= Significant at 5% level of probability; Capsule plant-1 (no.) within the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

Appendix III: Combined effect of Sulphur and Boron level on pod length

Treatment	Pod length (cm)
S0B0	3.66^{d}
S0B1	3.79^{c}
S0B2	3.85^{bc}
S0B3	3.89^{b}
S1B0	3.95^{b}
S1B1	4.04^{ab}
S1B2	4.12^{ab}
S1B3	4.16^{a}
S2B0	4.08^{ab}
S2B1	4.15^{a}
S2B2	4.2^{a}
S2B3	4.19^{a}
S3B0	4.17^{a}
S3B1	4.16^{a}
S3B2	4.17^{a}
S3B3	4.19^{a}
Level of significance	*

*= Significant at 5% level of probability; Capsule plant-1 (no.) within the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

Appendix IV: Combined effect of Sulphur and Boron capsule/plant

Treatment	Capsule plant-1 (no.)
S0B0	228[f]
S0B1	230.2[e]
S0B2	230.8[e]
S0B3	234.3[c]
S1B0	228.9[f]
S1B1	230.5[e]
S1B2	232.6[d]
S1B3	235.5[c]
S2B0	237.4[b]
S2B1	238[b]
S2B2	238.4[b]
S2B3	241.3[a]
S3B0	237[b]
S3B1	239.8[ab]
S3B2	241[a]
S3B3	240[ab]
Level of significance	*

*= Significant at 5% level of probability; Capsule plant-1 (no.) within the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

Appendix V: Combined effect of Sulphur and Boron on number of seed/capsule

Treatment	Seed capsule^{-1} (no.)
S0B0	9.29^{d}
S0B1	9.34^{d}
S0B2	9.57^{d}
S0B3	10.43^{cd}
S1B0	9.38^{d}
S1B1	10.82^{cd}
S1B2	11.48^{c}
S1B3	11.48^{c}
S2B0	10.43^{cd}
S2B1	12.32^{bc}
S2B2	15.9^{a}
S2B3	15.75^{a}
S3B0	10.35^{cd}
S3B1	12.14^{bc}
S3B2	13.63^{b}
S3B3	13.5^{b}
Level of significance	*

*= Significant at 5% level of probability; Seed capsule-1 (no.) within the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

Appendix VI: Combined effect of Sulphur and Boron level on seed weight

Treatment	1000-seed weight (g)
S0B0	8^{f}
S0B1	9.2^{e}
S0B2	10.7^{cd}
S0B3	11.5^{c}
S1B0	10.8^{cd}
S1B1	9.3^{e}
S1B2	10^{d}
S1B3	10.4^{d}
S2B0	10.9^{cd}
S2B1	11.7^{c}
S2B2	13.3^{b}
S2B3	15.4^{a}
S3B0	12.8^{bc}
S3B1	13.6^{b}
S3B2	14^{ab}
S3B3	14.5^{a}
Level of significance	*

*= Significant at 5% level of probability; 1000-seed weight within the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

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Appendix VII: Combined effect of Sulphur and Boron on grain yield

Treatment	Grain yield (kg ha^{-1})
S0B0	1806^{h}
S0B1	1842^{fg}
S0B2	1879^{f}
S0B3	2048^{c}
S1B0	1925^{e}
S1B1	1992^{d}
S1B2	1984^{d}
S1B3	2037^{cd}
S2B0	1939^{de}
S2B1	1925^{e}
S2B2	2050^{c}
S2B3	2180^{a}
S3B0	2170^{a}
S3B1	2140^{b}
S3B2	2170^{a}
S3B3	2150^{ab}
Level of significance	*

*= Significant at 5% level of probability; Grain yieldwithin the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

Appendix VIII: Combined effect of Sulphur and Boron on stover yield

Treatment	Stover yield (kg ha^{-1})
S0B0	2726^{e}
S0B1	2748^{d}
S0B2	2762^{c}
S0B3	2772^{bc}
S1B0	2791^{b}
S1B1	2745^{d}
S1B2	2760^{cd}
S1B3	2777^{bc}
S2B0	2781^{b}
S2B1	2769^{c}
S2B2	2763^{c}
S2B3	2747^{d}
S3B0	2779^{bc}
S3B1	2800^{a}
S3B2	2752^{cd}
S3B3	2761^{c}
Level of significance	*

*= Significant at 5% level of probability; Stover yieldwithin the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

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Appendix IX: Combined effect of Sulphur and Boron on harvesting index

Treatment	Harvest index (%)
S0B0	39.1^{e}
S0B1	39^{f}
S0B2	39.6^{cd}
S0B3	40^{b}
S1B0	39.9^{b}
S1B1	39.5^{d}
S1B2	39.8^{bc}
S1B3	39.8^{bc}
S2B0	40.1^{ab}
S2B1	39.4^{de}
S2B2	39.9^{b}
S2B3	40.3^{a}
S3B0	40.1^{ab}
S3B1	39.7^{c}
S3B2	39.6^{cd}
S3B3	39.3^{e}
Level of significance	*

*= Significant at 5% level of probability; Harvest indexwithin the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

Appendix X: Combined effect of Sulphur and Boron on nutrient contents in stover and seed

Treatment	Nitrogen (%)		Protein (%)		Phosphorous (%)		Potassium (%)		Sulphur (%)		Boron (ppm)		Oil content (%)
	Stover	Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover	Seed	seed
S0B0	1.20^{d}	3.41^{cd}	7.50^{i}	21.31^{g}	0.21^{d}	0.45^{b}	2.41^{cd}	1.09^{c}	0.08^{d}	0.52^{cd}	42.11^{f}	47.67^{fg}	41.67^{d}
S0B1	1.22^{cd}	3.43^{cd}	7.62^{h}	21.44^{f}	0.21^{d}	0.46^{b}	2.43^{c}	1.09^{c}	0.11^{cd}	0.57^{c}	42.38^{ef}	47.79^{f}	41.69^{d}
S0B2	1.26^{cd}	3.43^{cd}	7.87^{g}	21.44^{f}	0.24^{cd}	0.46^{b}	2.44^{c}	1.10^{c}	0.12^{cd}	0.57^{c}	42.67^{e}	47.99^{f}	41.83^{c}
S0B3	1.29^{c}	3.45^{c}	8.06^{f}	21.56^{ef}	0.26^{c}	0.47^{b}	2.47^{c}	1.11^{c}	0.13^{cd}	0.61^{bc}	42.99^{e}	48.46^{f}	41.88^{c}
S1B0	1.23^{cd}	3.44^{c}	7.69^{h}	21.5^{ef}	0.27^{c}	0.46^{b}	2.51^{bc}	1.10^{c}	0.14^{c}	0.63^{bc}	43.18^{d}	48.93^{f}	42.87^{bc}
S1B1	1.31^{c}	3.48^{c}	8.19^{de}	21.75^{e}	0.29^{c}	0.46^{b}	2.51^{bc}	1.14^{c}	0.15^{c}	0.67^{b}	43.23^{d}	50.12^{de}	42.88^{bc}
S1B2	1.34^{b}	3.53^{b}	8.37^{de}	22.06^{d}	0.36^{ab}	0.47^{b}	2.55^{b}	1.17^{c}	0.16^{c}	0.67^{b}	43.34^{d}	51.34^{de}	42.97^{b}
S1B3	1.37^{b}	3.55^{b}	8.56^{d}	22.19^{cd}	0.37^{ab}	0.48^{b}	2.56^{b}	1.23^{b}	0.17^{c}	0.67^{b}	43.88^{cd}	52.67^{d}	43.01^{b}
S2B0	1.31^{c}	3.48^{c}	8.19^{de}	21.75^{e}	0.35^{b}	0.47^{b}	2.58^{b}	1.25^{ab}	0.18^{c}	0.68^{b}	43.97^{cd}	52.89^{d}	43.73^{b}
S2B1	1.41^{ab}	3.56^{b}	8.81^{c}	22.25^{cd}	0.39^{ab}	0.52^{ab}	2.61^{ab}	1.29^{ab}	0.24^{b}	0.71^{ab}	44.89^{c}	54.62^{c}	43.75^{b}
S2B2	1.44^{a}	3.59^{ab}	9.00^{bc}	22.44^{c}	0.41^{a}	0.55^{a}	2.63^{ab}	1.34^{a}	0.29^{ab}	0.72^{ab}	45.65^{b}	57.17^{b}	43.78^{b}
S2B3	1.51^{a}	3.69^{a}	9.44^{a}	23.06^{a}	0.44^{a}	0.57^{a}	2.68^{a}	1.38^{a}	0.38^{a}	0.79^{a}	46.89^{a}	59.89^{a}	43.80^{b}
S3B0	1.40^{ab}	3.63^{ab}	8.75^{d}	22.69^{b}	0.42^{a}	0.55^{a}	2.67^{a}	1.35^{a}	0.33^{ab}	0.76^{a}	46.46^{ab}	59.18^{b}	44.90^{a}
S3B1	1.45^{a}	3.63^{ab}	9.06^{b}	22.69^{b}	0.43^{a}	0.56^{a}	2.67^{a}	1.36^{a}	0.37^{a}	0.79^{a}	46.68^{ab}	59.33^{ab}	44.93^{a}
S3B2	1.46^{a}	3.65^{a}	9.12^{b}	22.81^{ab}	0.43^{a}	0.55^{a}	2.68^{a}	1.37^{a}	0.36^{a}	0.78^{a}	46.78^{a}	59.92^{a}	44.95^{a}
S3B3	1.49^{a}	3.69^{a}	9.31^{ab}	23.06^{a}	0.44^{a}	0.56^{a}	2.68^{a}	1.38^{a}	0.36^{a}	0.78^{a}	46.87^{a}	59.98^{a}	44.98^{a}

Mean value within the column with different superscripts are significantly different; S0B0= control; S0B1= 0 kg S and 1 kg B; S0B2= 0 kg S and 2 kg B; S0B3= 0 kg S and 3 kg B; S1B0= 10 kg S and 0 kg B; S1B1= 10 kg S and 1 kg B; S1B2= 10 kg S and 2 kg B; S1B3= 10 kg S and 3 kg B; S2B0= 20 kg S and 0 kg B; S2B1= 20 kg S and 1 kg B; S2B2= 20 kg S and 2 kg B; S2B3= 20 kg S and 3 kg B; S3B0= 30 kg S and 0 kg B; S3B1= 30 kg S and 1 kg B; S3B2= 30 kg S and 2 kg B; S3B3= 30 kg S and 3 kg B.

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