EFFECT OF SULPHUR AND ZINC FERTILIZER ON THE GROWTH AND YIELD OF CHILI (BARI MORICH 4)

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CERTIFICATE

This is to certify that the thesis entitled "**EFFECT OF SULPHUR AND ZINC FERTILIZER ON GROWTH AND YIELD OF CHILI (BARI MORICH 4)**" 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 (M.S.)** in **SOIL SCIENCE**, embodies the results of a piece of bona fide research work carried out by **NUSHRAT JAHAN SUNY**, **Registration. No. 15-06847**, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma in any other institution.

I further certify that any help or sources of information received during the course of this investigation have been duly acknowledged.

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Dedicated
To My
Beloved Parents
And
Honorable Teachers

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ABSTRACT

The experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka, during the Rabi season from November, 2021 to April, 2022 to investigate the effect of sulphur (S) and zinc (Zn) fertilizer on green chili production (cv. BARI Morich 4). The experiment consisted of two factors, *viz.*, Factor A: 3 levels of Sulphur (S_0: 0 kg ha^{-1}, S_1: 20 kg ha^{-1}, S_2: 30 kg ha^{-1}) and Factor B: three levels of zinc (Zn_0: 0 kg ha^{-1}, Zn_1: 2 kg ha^{-1} and Zn_2: 4 kg ha^{-1}). Two factor experiments with Randomized Complete Block Design was followed with 9 treatment combination and replicated three times. Vegetative growth, yield contributing characters and yield were measured during the experiment. In case of S treatment, the tallest plant (66.12 cm), number of leaves plant^{-1} (96.13), number of branches plant^{-1} (15.50) were observed at 80 DAT and the highest number of fruits plant^{-1} (104.57), flowers plant^{-1} (111.18), fruit length (7.10 cm), fruit diameter (0.56 cm), individual fruit weight (1.73 g), average fruit weight plant^{-1} (177.27 g), fruit yield ha^{-1} (28.21 t) were obtained from S_1 treatment. In case of Zn treatment, the tallest plant (66.06 cm), number of leaves plant^{-1} (92.61), number of branches plant^{-1} (14.76) were observed at 80 DAT, the highest number of flowers plant^{-1} (109.24), fruits plant^{-1} (98.81), fruit length (6.93 cm), fruit diameter (0.58 cm), individual fruit weight (1.69 g), average fruit weight plant^{-1} (169.05 g) and fruit yield ha^{-1} (27.35 t) were recorded from Zn_2 treatment. Considering combined effect of S and Zn, growth contributing parameter such as the tallest plant (74.83 cm), number of leaves plant^{-1} (101.32), maximum number of branches plant^{-1} (16.74), highest number of flowers plant^{-1} (121.26), maximum number of fruits plant^{-1} (114.09), highest fruit length (7.79 cm), highest fruit diameter (0.63 cm), highest individual fruit weight (1.78 g), average fruit weight plant^{-1} (203.49 g) and fruit yield ha^{-1} (33.52 t) were recorded from S_1Zn_2. Meanwhile, the lowest values of the parameters were found in the control application of sulphur and zinc. Therefore, it can be concluded that 20 kg ha^{-1} of sulphur and 4 kg ha^{-1} of zinc were found beneficial for growth and yield of green chili.

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LIST OF ABBREVIATIONS

AEZ	:	Agro-Ecological Zone
BARI	:	Bangladesh Agricultural Research Institute
BBS	:	Bangladesh Bureau of Statistics
CV%	:	Percentage of Co-efficient of Variance
Cv.	:	Cultivated variety
DAT	:	Days after transplanting
et al.	:	And others
EC	:	Electrical conductivity
FAO	:	Food and Agriculture Organization of United Nations
fed.	:	Feddan (1.038 acres)
g	:	gram
ha^{-1}	:	Per hectare
HRC	:	Horticulture Research Centre
i.e.	:	That is
kg	:	Kilogram
LSD	:	Least Significant Difference
lb.	:	British pound
Max	:	Maximum
Min	:	Minimum
MoP	:	Muriate of Potash
N	:	Nitrogen
NPK	:	Nitrogen, Phosphorous and Potassium
PSB	:	Phosphate Solubilizing Biofertilizer
RCBD	:	Randomized Complete Block Design
SAU	:	Sher-e-Bangla Agricultural University
spad	:	Soil Plant Analysis Development (Chlorophyll meter unit)
SRDI	:	Soil Resources and Development Institute
TSP	:	Triple Super Phosphate
wt.	:	Weight
%	:	Percent

Chapter I

Introduction

Chapter I

INTRODUCTION

Chili (*Capsicum annum* L.) is an important spice crop which belongs to the family, Solanaceae which is also called nightshade family. In this family, after tomato and potato, chili is the 3rd most significant crop. In Bangladesh, chilies are cultivated on commercial scale, covering the largest area after onion and potato. Economically, chilies are grown as cash crop. The genus *Capsicum* contains almost 20 species and among them only 5 species are cultivated, out of that *Capsicum frutescence* and *Capsicum annuum* is regularly cultivated all over the world (Khan, 2014). *Capsicum frutescence*, also called hot peppers, has an extra amount of alkaloid capsaicin ($C_{18}H_{27}O_3$) which is responsible for the pungency (Udoh *et al.*, 2005). Chili is the universal spice and that is widely cultivated throughout temperate, tropical and subtropical countries. The ground powder and oleoresin are practiced in pharmaceutical preparations (Warrier, 1989). Total annual production of Rabi chili in Bangladesh is about 79747 metric tons from 426157 acres of land Chilies are grown in all the districts of the country but plenty of chilies are produced in the district of Bogura, Rangpur, Kurigram, Natore, Jamalpur and Jashore (BBS, 2019). Usually the chili farmers of Bangladesh use local cultivars for the production of chili which produce very low yields. The main reasons of low yield are lack of adopting new cultivation techniques and improper fertilization to enhance the production of the chili, it is necessary to pay attention on balanced use of nutrient through fertilizer application. Growers and farmers need to manage the fertilizer for better quality of fruit production. One of the reasons of lower yield might be imbalanced use of fertilizers and manure and low levels of available Zn and S in the soils of major chili growing areas.

Chilies are very rich in vitamin C and pro-vitamin A, particularly the red chilies. Yellow and especially green chilies (which are essentially unripe fruit) contain a considerably lower amount of both substances. In addition, peppers are a good source of most B vitamins, and vitamin B_6 in particular. They are very high in potassium and high in magnesium and iron. Their high vitamin C content can also substantially increase the uptake of non-heme iron ingredients in a meal, such as beans and grains. Chemical analysis of chili have shown that red chili fruit contains 15.9% protein, 31.6% carbohydrate, 50 mg/100g vitamin-C and small quantities of vitamin A, B and E (Litoria *et al.*, 2014).

It is realized that productivity of crop is being adversely affected in different areas due to deficiencies of micronutrients (Bose and Tripathi, 1996). The deficiency of micronutrients increased markedly due to intensive cropping, loss of top soil by erosion, loss of micronutrients by leaching, liming of soil and lower availability and use of farm yard manure (Fageria *et al.,* 2002). Micronutrients are usually required in minute quantities, nevertheless are vital to the growth of plant (Benepal, 1967). Improvement in growth characters as a result of application of micronutrients might be due to the enhanced photosynthetic and other metabolic activity which leads to an increase in various plant metabolites responsible for cell division and elongation as opined by Hatwar *et al.* (2003).

Sulphur is a plant nutrient with a crop requirement similar to that of phosphorus. Sulphur is known as the fourth major plant nutrient (Jamal *et al.,* 2010). Sulphur (S) is one of the essential macro elements of plant and is regarded as the fourth key element after N, P and K (Lewandowska and Sirko, 2008). Most often S deficiencies are observed in low OM soils and coarse-textured soils where S can be easily leached out. It is used as a soil amendment to improve the availability of nutrients such as P, K, Zn, Mn and Cu (Hassaneen, 1992) where they found that sulphur element reduced pH and conversed the unavailable phosphorus to available form for plant tissues. Sulphur is required for the synthesis of important essential amino acids by increasing allyl propyl disulphide alkaloid (43% S) and the capsaicin which is the principal alkaloids responsible for pungency in onion and sweet pepper respectively and also it makes a key role in the defense of plants against nutrients stress, attacks of pests and increases the synthesis of chlorophyll and vitamins in the cell (Hasseneen, 1992). This essential constituent of Sulphur containing amino acids cystine, cysteine and methionine and plays vital role in regulating the metabolic and enzymatic process including photosynthesis, respiration and symbiotic N fixation, besides being responsible for the synthesis of vitamins such as biotin, thiamine, vitamin B and certain coenzymes (Kumar and Singh, 2009). It has been observed when sulphur is present in critical amount of soil (less than 10 ppm), the plant growth, quality and total production of crop is adversely affected (Jones *et al.,* 1984).

Zinc (Zn) plays a vital role for successful green chili production. Zinc exerts a great influence on basic plant life process such as nitrogen metabolism, photosynthesis, protein quality and resistance to abiotic and biotic resistance in plants (Potarzycki, and Grzebisz, 2009). Zn involved in auxin (IAA) metabolism like, tryptophane synthesis, tryptamine metabolism, protein synthesis, formation of nucleic acid and helps in utilization of nitrogen as well as phosphorus by plants (Ram and Katiyar, 2013). In plant deficiency of $ZnSO_4$ affects various plant metabolic processes such as nitrogen uptake, photosynthetic activity, nitrogen metabolism chlorophyll synthesis and protein quality (Cakmak, 2008).Singh *et al.* (1989) observed that higher plant height with application of zinc sulphate as well as foliar spray. Application of zinc at the rate of 3 ppm noticed maximum number of leaves and number of roots plant^{-1} (Sindhu and Tiwari, 1989) and soil plus foliar application of zinc sulphate each at 20 kg ha^{-1} and 0.5% respectively produced maximum number of branches plant^{-1} (7.52) (Singh *et al.*, 1989) where application of $ZnSO_4.7H_2O$ received by chili at 20 kg per ha enriched with vermicompost recorded the highest yield (Patil *et al.*, 2011). One of the reasons of lower yield might be imbalanced use of fertilizers and manure and low levels of available Zn in the soils of major chili growing areas (Bose and Tripathi, 1996).

Sulphur is essential for production of protein, fats and oils, promotes enzyme activity and helps in chlorophyll formation, improves root growth and grain filling resulting in vigorous plant growth and resistance to cold. Zinc (Zn) also played a vital role for successful green chili production. Singh *et al.*, (1989) observed that higher plant height with soil application of zinc sulphate as well as foliar spray. Its deficiency causes interveinal chlorosis with a very distinct reddish color of the veins and petioles (Shanyan and Lucy, 1999). Sulphur application in vegetable crops have been found to improve quality attributes, protein content, oils and vitamins (Dhar *et al*., 1999 and Sriramchandra, 2009). Sulphur also helps in improving the nutrient content and uptake of nutrients in legume crops (Singh and Singh, 1992).

Zinc plays a crucial role in the activation of enzymes involved in sulphur metabolism, such as adenosine-5'-phosphosulfate reductase (APR). This enzyme catalyzes the reduction of adenosine-5'-phosphosulfate (APS) to sulfite, which is a key step in sulphur assimilation. Zinc deficiency can limit the activity of APR, impairing the plant's ability to utilize sulphur effectively. This can result in reduced synthesis of essential sulphur-containing compounds like cysteine and methionine. Sulphur availability in the soil can affect the solubility and bioavailability of zinc. Adequate sulphur levels can enhance zinc availability by maintaining an optimal soil pH and promoting the formation of soluble zinc-sulphur complexes.

The present research was conducted to find out the optimum levels of sulphur and zinc for growth, yield and quality of chili crop. Although, many experiment have been carried out on nutrient requirement of chili but few reports are found on the sulphur and zinc fertilizer requirement and the combined effects of these element on chili. From this point of view, the experiment was conducted at Sher-e-Bangla Agricultural University farm under the Agro Ecological Zone of Madhupur Tract (AEZ-28) with the following objectives:

- To investigate the effect of S and Zn fertilizer on the growth parameters and yield of chili.
- To find out the optimum dose of S and Zn fertilizer for proper growth and yield of chili.

Chapter II

Review of Literature

YuChapter II

REVIEW OF LITERATURE

Nutrient deficiency in soil is the key factor for poor productivity of chili. The extent and magnitude of nutrient deficiency has aggravated in the recent past due to intensive agriculture and indiscriminate use of plant nutrients. Although many research works on chili have been performed extensively in several countries in the world, in Bangladesh, little attention has so far been given for the improvement of chili variety or its cultural management. Currently Bangladesh Agricultural Research Institute (BARI) and Bangladesh Institute of Nuclear Agriculture (BINA) have started extensive research work on varietal development and improvement of this crop. A very few studies related to yield and development of chili have been carried out in our country as well as many other countries of the world, which is not adequate and conclusive. In this chapter, an attempt has been made to review the available information at home and abroad regarding the effect of S and Zn on the yield of chili and other solanaceae.

2.1 Effect of sulphur

Islam (1987) found Sulphur is very much beneficial for increasing the production of vegetable and rice. Sulphur deficiency delays growth and development of plant.

Nasreen *et al.* (1989) carried out a field experiments at the Bangladesh Agricultural Research Institute farm, Joydebpur during the winter season (rabi) in 1985-86 and 1986-87 to determine the response of chili to different levels of fertilizers. Results showed significant influence of fertilizer on the plant height, number of branches and fruits plant^{-1} as well as yield (dry fruits). Nitrogen and phosphorus were more effective in increasing the yield than other nutrients. Potassium and sulphur had no significant effect. The highest yield of chili was obtained with 120-90-90-10 kg NPKS ha^{-1}.

Konopinski (1995) in an experiment found S in Naga chili plants effects in the synthesis of glucosinolates, typical compounds determining the flavor of fruits. S deficiency affects photosynthesis, the synthesis of protein, vitamins and can reduce yields and quality of crops.

Xu *et al.* (1996) conducted experiment shows that sulphate accumulates in the rhizosphere of plants grown in hydroponic systems. To avoid such sulphate accumulation and promote the use of environmentally sound hydroponic systems, we examined the effects of four sulphate concentrations (0.1, 5,2, 10.4 and 20.8 mM) on photosynthesis, ribulose-l,5-bisphosphate carboxylase/oxygenase (Rubisco, EC 4.1.1.39) activities and related physiological processes in greenhouse–grown tomato plants (*Lycopersicon esculentum* Mill. cv. Trust). The lowest sulphate concentration (0.1 mM) significantly decreased photosynthetic capacity (P c) and Rubisco activities on a leaf area basis. This result was supported by our data for dry matter plant^{-1}, which was low for plants in the 0.1 mM treatment. The photosynthesis-related variables such as leaf conductance, chlorophyll and soluble protein were lowest for the 0.1 mM treatment. Both total Rubisco activity and the activated ratio were reduced with this treatment.

Kayser *et al*. (2000) demonstrated that the application of elemental Sulphur increased zinc solubility in the soil and utilization by plants. Different results were obtained by Abdou *et al*. (2011) who did not observe an increase in zinc availability to plants as a result of elemental sulphur fertilization.

Jaggi *et al.* (2003) conducted a pot culture experiment to compare the performance of S-containing and non-containing P fertilizers on chili (*C. annuum* cv. Surajmukhi) grown on acid Alfisol. Mussoorie rock phosphate (MRP) in combination with 37.5 ppm S, and single superphosphate (SSP) in combination with 12.5 ppm S were superior in terms of dry chili weight and ratoon yield. The effect of the fertilizers on the number of chilies was significant only in 1997. MRP + 37.5 ppm S and SSP + 12.5 ppm S resulted in the highest number of chilies per 20 kg weight.

Islam (2006) conducted a field experiment at the Horticultural Farm, BAU, Mymensingh during the period from November 2005 to February 2006, to study the effect of plant nutrients on growth and yield of carrot. It was found that the highest gross yield (54.11 t ha^{-1}) was produced by the treatment combination $N_{113}P_{33}K_{75}S_2$ + Zn_7 kg ha^{-1}, while the highest marketable yield of carrot (49.394 t ha^{-1}) was obtained from the treatment combination of $N_{113}P_{33}K_{75}S_2$ + Zn_7 kg ha^{-1}.

Santos *et al.* (2007) conducted two field studies to determine the effect of S fertilization on tomato (*Lycopersicon esculentum* Mill.) yield and foliar S concentration. The soil had very low S content (<30 ppm) and 1.5% organic matter. Fertilizer sources were: 1) ammonium nitrate (AN; 34% N) at a rate of 300 lb. acre^{-1} of N; 2) AN + potassium sulfate (PS; 23% S and 55% K> at rates of 300 + 343 lb. $acre^{-1}$ of N and S: 3) ammonium sulfate nitrate (ASN; 26% N and 16 14% S) at a rate of 300 + 343 lb. $acre^{-1}$ of N and S: 4) Non-treated control. Plots treated with either rate of AN or non-treated had the lowest foliar S concentration, ranging between 0.55% and 0.53%. However, plots treated with S-containing fertilizers increased foliar S concentration when compared with the non-treated control and AN-treated tomatoes. Average S concentration was about 0.74%, which was 40% higher than the concentration in non-treated control plots. There were no significant marketable yield differences in plots treated with either AN + PS or ASN. Average marketable yield ranged between 27.5 and 28.2 ton/acre in the S-treated plots. In contrast, average yield in the AN-treated plots was 18.7 ton/acre, which was 44% and 42% less than the yields in the AN + PS and ASN-treated plots.

Saeed and Ahmad (2009) carried out a study to observe the effects of organic mulch with and without gypsum on vegetative growth and reproductive yield of tomato plant (*Lycopersicon esculentum* Mill. cv. F_1 Avinash) under control (non-saline) and saline rhizosphere. Plant height, fresh and dry vegetative biomass, number of flower and fruit cluster $plant^{-1}$, number of flower and fruit $cluster^{-1}$, number and weight of fruit $plant^{-1}$ and circumference of fruit showed comparatively higher growth at all the parameters in T_4 (mixture of mulch and gypsum) followed by T_3 (gypsum alone), T_2 (mulch alone) and T_1 (control without mulch or gypsum) under saline as well as non-saline conditions. Application of organic mulches with or without gypsum to soil being irrigated with saline water increases the yield by reducing salinity hazards which could be quantified on growth of tomato plant.

Kaya (2009) reported that increased application of sulphur and sulphur-containing waste led to a significant increase in copper content of plants. Elemental Sulphur is biologically oxidized to H_2SO_4 in soil under aerobic conditions. The oxidation of S to H_2SO_4 is particularly beneficial in alkaline soils to reduce pH, make micronutrients more available and reclaim soils. They also reported a significant positive correlation between the SO_4-S content and electrical conductivity (EC) of tomato greenhouse soils. The generated soil salinity was high with increasing sulphur applications, which indicates that plants might be subjected to high salinity problems. High rates of elemental sulphur should be avoided, especially in soils with high EC level. Soil properties (especially EC and pH) and cultivated plant species should be taken into consideration in the recommendations for sulphur application to soils.

Takac *et al*. (2009), stated that sulphur fertilization had significant effect on changes in the Cu content of soil which could result from changes in soil pH. In a study carried out by the content of mobile Cu in the soil was not significantly affected by soil pH. Soil pH is known to regulate bioactivity and availability of nutrients to plants, because H^+ protons are involved in chemical equilibrium. Vicente *et al*. (2009) and Jaggi *et al*. (2003) claimed that the availability of copper to plants, as with other trace minerals, markedly decreases as pH value rises. At high pH value copper is strongly adsorbed to clays, iron and aluminum oxides, and organic matter.

Abdou *et al*. (2011) researched elemental sulphur fertilization increased Mn concentrations in the soil, in comparison with the control. The application of 400 kg sulphur contributed to an increase in Mn content (5.41mg kg^{-1}), compared with other Sulphur doses. One of the adverse effects of sulphur contamination is an increase in Mn solubility and the mobilization of heavy metals from both natural and anthropogenic sources.

Islam *et al.* (2013) a pot experiment was laid out in completely randomized design with 12 treatments and 3 replications using four (0, 30, 60 and 90 kg P ha) levels of P and three (0, 15 and 30 kg S ha) levels of S. Urea, muriate of potash, boric acid, zinc oxide, cow dung and poultry manure were applied with all the treatments as basal dose according to the fertilizer recommendation guide. The study revealed that yield and yield attributes such as plant height, no. of branches, no. of leaves, no. of flowers, no. of fruits, fruit length, fruit diameter, fruit weight, vitamin C and protein content of brinjal were significantly influenced by P, S and their interactions. Plant height, number of branches, leaves, flowers and fruits were increased 90, 60, 120 and 105 days after transplanting (DAT), respectively and then either decreased or remained constant. The highest values of all the parameters were obtained from P_{60} and S_{30} treatments except the vitamin C content which was maximum in P_{30} and S_{15} treatment. The results suggest that P and S @ 60 and 30 kg ha^{-1} along with basal doses of other inorganic fertilizers and organic manures can be used to increase brinjal yield and vitamin C content under the agro climatic condition of BAU.

Klikocka and Głowacka (2013) conducted an experiment on the impact of sulphur fertilization on content of Mg and Ca in the dry-mass and in yield of dry-mass of potato tuber. The work was done by applying different kinds of sulphur (elemental and K_2SO_4)

and rate (0, 25 and 50 kg ha^{-1}). The highest content of Mg and Ca was found when using 25 kg S ha^{-1} in elemental kind and 50 kg S ha^{-1} in elemental and sulphur kind. Sulphur fertilization in sulphate kind increased content S-SO_4 in the soil, while S-elemental fertilization in rate 50 kg ha^{-1} decreased pH value of soil.

Silva *et al*. (2014) arranged the experiment with 6 doses of S (0, 20, 40, 60, 80 and 100 mg kg^{-1}) in the form of agricultural gypsum in tomato plant cv. Abiru variety. The tomato fruit production increased under sulphur doses and highest from 80 mg kg^{-1}, obtaining a 23 to 34% raise. The dry mass of the shoot, content and accumulation increased under the application of sulphur doses on the soil.

Poornima *et al.* (2016) carried out a field experiment on black clay soil to study the effect of potassium and sulphur on onion and chili intercrops in a vertisol with four levels of potassium (0, 50, 75 and 100 kg K_2O ha^{-1}) and three levels of sulphur (0, 15 and 30 kg S ha^{-1}). The significantly higher uptake of N, P, K and S by onion plant as well as shoot and fruit portion of chili were observed with the individual application of potassium @ 100 kg K_2O ha^{-1} and sulphur @ 30 kg S ha^{-1}.

Orman and Kaplan (2017) conducted an experiment and evaluated the effects of elemental sulphur and farmyard manure on agronomic bio fortification within the parameters of N, P, S and N:S ratio in green bean (*Phaselous vulgaris* L.). Sulphur 0 (S_0), 50 (S_1), 100 (S_2), 150 (S_3), 200 (S_4), 400 (S_5) mg kg^{-1} and farmyard manure 0 (FYM_0), 3 (FYM_1) t ha^{-1} were applied. The soil pH was decreased while EC was increased by the applications of S and FYM. The P concentration of shoot was increased by S with FYM. While the dry weight and S concentration of shoot were increased, N concentration was slightly decreased by S, alone. The N: S ratio decreased from 23.76 in S_0FYM_0 to 15.93 in S_5FYM_1. All results indicate that sulphur applications in S_1 and S_2 levels with farmyard manure can be sufficient for growing bean in the soil.

Sati *et al.* (2017) found that basal and/or split application of zinc sulphate at 25 kg ha^{-1} improved potato tuber quality under present agro-climatic conditions.

Solanki *et al.* (2017) conducted a field study aimed to explore in detail the effect of zinc and boron on growth, yield and quality of brinjal (*Solanum melongena* L.). The individual treatment of 5 mg zinc, 10 mg zinc, 5 mg boron and 10 mg boron and treatment combinations 5 mg Zn+5 mg B, 5 mg Zn+10 mg B, 10 mg Zn+5 mg B and

10 mg Zn+10 mg B per kg soil was given in brinjal pots, the growth parameters like plant height, number of leaves, number of branches, number of flowers and yield parameters like maximum number of fruits plant^{-1} was obtained in brinjal influenced by combination of treatments T_8 (10 mg Zn+10 mg B) and was significantly superior at 5 per cent over rest of the treatments.

Sameh and Lamia (2018) found that increasing sulphur and nitrogen fertilization levels improved most of the vegetative growth characters and total tuber yield per feddan, but also increased the levels of acrylamide in processed potato. Four levels of sulphur fertilizer (0, 100, 200 and 300 kg S fed.$^{-1}$ = 4200 m^2) and two levels of nitrogen fertilizer (100 and 200 kg N fed.$^{-1}$) were applied to the growing potato plants. The best results for the vegetative growth traits and total tuber yield/fed could be achieved from the application of 300 kg S fed.$^{-1}$ + 200 kg N fed.$^{-1}$ Levels of acrylamide in potato processed were significantly increased by increasing nitrogen fertilizer treatments from 100 up to 200 kg N fed.$^{-1}$ or increasing sulphur treatments from 100 kg up to 300 kg S fed.$^{-1}$.

Fantaw *et al.* (2019) a field experiment was conducted from 2016-2018 with 9 combination of nitrogen, phosphorous and sulphur fertilizers arranged in randomized complete block design with three replications to assess response of potato to these rates. The application 110-19.74-50.8 kg ha^{-1} $N_2S_2P_2O_5$ fertilizer delayed days to flowering and maturity by 8 and 11 days at Darark and 10 and 14 days at Dabat. However, it increased plant height and number of stems plant^{-1}, which may positively contribute to increased photosynthetic area. The application of these fertilizers advanced marketable tuber yield by 153% and the total tuber yield by 86.6% relative to unfertilized plants. Furthermore, the partial budget analysis data showed that the highest net benefit and marginal rate of return (4453.6%) was obtained from 110-19.74-50.8 kg ha^{-1}.

Dhakad *et al.* (2019) carried out an investigation to study the effect of levels of sulphur in combination of organic and inorganic sources of nutrient on plant growth and yield of potato (*Solanum tuberosum* L.). The treatment combinations of four levels of S application i.e. 30, 60, 90 and 150 kg ha^{-1} in combinations of 100% RDF and FYM. The study revealed that plant growth and yield of potato crop were significantly influenced by levels of sulphur application during both the years. Control treatment recorded maximum root length at all the stages of crop growth during both the years (12.50, 12.25, 15.08, 13.56, 16.65 and 14.14 cm, respectively) as compared to other treatments. Application of 100% RDF + FYM @ 25 t ha^{-1} gave higher value of fresh root weight/plant at all the stage of crop growth as compare to other treatments during both the years (1.12, 1.25, 2.24, 1.80, 1.97 and 1.66 g plant^{-1}, respectively). Application of 100% RDF + FYM @ 25 t ha^{-1} + 30 kg S recorded higher fresh haulm yield (19.56 and 17.54/12.0 m^{2}) and treatment 100% RDF NPK + FYM @ 25 t ha^{-1} recorded higher fresh tuber yield (43.22 and 45.84 kg/12.0 m^{2}) and biological yield (62.06 and 63.16 kg/12.0 m^{2}) as compare to other treatments during both the years. This treatment was at par with 100% RDF + FYM @ 25 t ha^{-1} + 30 kg S during both the years.

Miyu *et al.* (2019) carried out a field experiment on effect of foliar application of micronutrients on potato for growth, yield and quality. Under eight treatment T_1 (control) [FYM (25 t ha^{-1}) + RDF (150:120:100 kg NPK ha^{-1}], T_2 (control + 0.1% Borax), T_3 (control + 0.2% Zinc Sulphate), T_4 (control + 0.2% Manganese Sulphate), T_5 (control + 0.1% Borax + 0.2% Zinc Sulphate), T_6 (control + 0.1% Borax + 0.2% Manganese Sulphate), T_7 (control + 0.2% Zinc Sulphate + 0.2% Manganese Sulphate) and T_8 (control + 0.1% Borax + 0.2% Zinc Sulphate + 0.2% Manganese Sulphate). The result revealed that, for growth parameters T_8 (T_1 or control + 0.1% Borax + 0.2% Zinc Sulphate + 0.2% Manganese Sulphate) was found to be the best. For yield attributes, T_6 (T_1 or control + 0.1% Borax + 0.2% Manganese Sulphate) and T_8 (T_1 or control + 0.1% Borax + 0.2% Zinc Sulphate + 0.2% Manganese Sulphate) were found to be the best.

Mekashaw *et al.* (2020) laid a field experiment to evaluate the effects of blended NPS fertilizer rates on yield and yield components of potato. The study was conducted at Abaso Kotu, Dessie Zuria district, Ethiopia, during dry season of 2015. The experiment was consisted a factorial combination of two late maturing potato varieties (Belete and Local) and six NPS fertilizer rates (0:0 (T_1), 111:89.7:0 (T_2), 111:89.7:16.52 (T_3), 55:89.7:16.52 (T_4), 111:44.85:8.26 (T_5) and 55:44.85, 8.26 (T_6)) kg ha^{-1}. The highest potato plant height was recorded on 111: 89.7:16.52 (T_3) kg ha^{-1} of NPS fertilizer rate. Belete variety supplied with 111: 89.7:16.52 (T_3) kg ha^{-1} of NPS fertilizer rate recorded the maximum days (124.3) to maturity of potato. Similarly, Belete variety recorded the higher biomass than local variety. The 111:89.7:16.52 (T_3) kg ha^{-1} and 55.5:89.7:16.52 (T_4) kg ha^{-1} NPS fertilizer rates showed the highest above ground biomass and underground biomass of potato, respectively. The highest average tuber number per hill, tuber weight per hill, marketable, unmarketable and total tuber yield were recorded on potato which was applied with 55.5: 89.7:16.52 (T_3) kg ha^{-1} of NPS fertilizer rate. It is concluded that 55.5:89.7:16.52 (T_4) kg ha^{-1} NPS fertilizer rate application is recommended for the production of potato varieties at Abaso Kotu, Dessie Zuria District Ethiopia.

Yue *et al.* (2020) in an experiment used CS_2SMs as a new type of green sulphur fertilizer to promote the growth of eggplant, tomato, sweet pepper and cucumber. The experimental results showed that all CS_2SMs could promote plant height, stem diameter, root weight, flower bud number and leaf size. Especially, several CS_2SMs presented significant influence on fluorescence and fruit number. Further studies showed that the CS_2SMs as new energy resources sulphur-containing boosted leaf area, improved root development, enhanced photosynthesis and soil nutrient uptake, and promoted vegetative and reproductive growth of these four types of plants.

Viera *et al.* (2021) conducted experiment on an application of a balanced nutrition will improve the soil as well as enhance the yield of naranjilla (*Solanum quitoense* Lam.) grown in the Ecuadorian Amazon. A field experiment was carried out to find which variables are related with the yield of crop and the yield response when the crop receives complete nutrition with N, P, K, Ca, Mg, and S plus lime and with the omission of each of these nutrients. The naranjilla crop had higher yields (18.14 Mg ha^{-1}) in the complete treatments (N, P, K, Ca, Mg, and S) and without S and Mg, consequently, these two last nutrients did not limit the production. When N, P, K, and Ca were not applied, the yields fell to 14.62 Mg ha^{-1}. The main environmental effect showed that Palora had the highest fruit yields (19.73 Mg ha^{-1}), followed by 16 de Agosto (13.57 Mg ha^{-1}) and finally Fátima with 11.04 (Mg ha^{-1}). These preliminary results showed that with the treatments without S (18.55 Mg ha^{-1}), without Mg (18.42 Mg ha^{-1}) and complete (17.46 Mg ha^{-1}) the highest yields were obtained, consequently, the production was not affected by the absence of these elements; the opposite happened when N, P, K, and Ca were not present.

Gokul *et al.* (2020) conducted a field experiment with chili variety K_2 as the test crop. The experimental soil was sandy clay loam. The treatments consisted of application of inorganic fertilizers, organic manures and biofertilizers in different combinations. The growth attributes and nutrient content were recorded at 60, 90 and 120 DAT. The results of the experiment revealed that the application of 75% recommended dose of fertilizers + poultry manure @ 5 t ha^{-1} + biofertilizers + 2% $MgSO_4$ (T_{11}) registered the maximum growth attributes (plant height, leaf area index, number of branches plant^{-1} , chlorophyll content) and nutrient content (N, P, K, Ca, Mg and S) of chili.

Hussein and Ahmed (2022) conducted field experiment on the effect of micronized sulphur on tomatoes in green house conditions. Spraying with micronized sulphur at a concentration of 5 cm^3L^{-1} recorded a significant increase in most of the characteristics of vegetative, flowering, yield and characteristics to 47.04 spad unit, 3.769%, 2.327%, 74.41 days, 2,300 kg respectively, compared to the control treatment which amounted to 45.01 spad, 3.007%, 2.050%, 77.16 days, 1.854 kg respectively.

2.2 Effect of zinc

Singh *et al*. (1989) conducted experiments has studied chili pepper growth and yield in relation to zinc content. Results showed higher plant height (40.47 cm) with soil application of zinc sulphate and foliar application (20 kg $ZnSO_4$ + 0.5% foliar application).

Sindhu and Tiwari (1989) conducted an experiment to examine the effects of micronutrients on G.B. chili (Cv. Pusa Red). As a result, they found that 3 ppm of zinc maximized the number of leaves and roots plant^{-1}. Similarly, the experiments by Singh *et al*. (1989) studied chili growth and yield in relation to zinc content. Results showed that soil and foliar applications of zinc sulphate produced maximum branch numbers at 20 kg ha^{-1} and 0.5% plant^{-1}, respectively (7.52).

Alpaslan *et al.* (1999) conducted an experiment in chili plant using non saline and saline (30 mM NaCl), Zn (10, 20, 40 mg kg^{-1}) and without Zn treatment and factorial combinations of NaCl and Zn on the fresh and dry weights of the plants, and sodium (Na), chloride (Cl) and zinc (Zn) contents of both young and old leaves were determined and the effects of Zn on the Na and Cl translocation within the plants were investigated. Salinity decreased the fresh and dry weights of the plants while this effect of salinity diminished with increasing Zn levels. Na and Cl concentrations of both young and old leaf tissues decreased with increasing levels of Zn treatment and these decreases were more pronounced in the presence of salinity. Zn treatment also decreased Na and Cl translocation from old leaves to young leaves. Zinc con-tent of the leaf tissues increased in both saline and non-saline conditions with Zn treatment. From the result of the present study, it was concluded that in the salt affected areas, zinc application could alleviate possible Na and Cl injury in chili.

Yadav *et al*. (2001) studied the effects of zinc sulfate application on the growth of Chili (Cv. Jaffa). Results showed a significant increase in plant height (10.71 cm) and plant spread (10.78 cm) with the application of 250 g plant^{-1} of zinc sulfate. Under control, a minimum of plant height (8.11 cm) and plant spread (7.40 cm) was recorded.

Dongre *et al*. (2000) conducted a field experiment on three micronutrients (Zn, Fe, B) were tried in three concentrations i.e. 0.1, 0.25 and 0.50% foliar spray. There were ten treatments replicated three times and applied at 30 and 60 days after transplanting. The observation on fruit yield plant^{-1} and quality of chili fruits plant^{-1} were recorded and analyzed statistically. The treatment T_3 ($ZnSO_4$ 0.50%) exhibited the maximum yield (111.75 q ha^{-1}) and treatment T_5 ($FeSO_4$ 0.25%) produced the maximum number of seeds fruit^{-1} (57.93).

Yogananda *et al*. (2004) conducted an experiment with ten grams seeds of bell pepper [*Capsicum annuum*] (cv. Slifornia Wonder) were soaked in 150 ml. solution each of gibberellic acid (GA_3). Significantly higher germination (91.05%) was obtained with T_3 compared with other concentrations of GA_3, combination of GA_3 + cytokinin treatments and T_7. However, these treatments recorded higher germination over T_0 (81.5%). Significantly longer root (5.55 cm) and shoot (7.50 cm), higher germination rate (12.75), seedling dry weight (53.5 mg) and seedling vigor index (1174) were obtained from seeds invigorated with T_3 compared to the control (4.27 cm, 5.75 cm, 9.04, 42.25 mg and 518, respectively). Seeds invigorated with the micronutrients significantly increased the seed germination. Among the micronutrients, T_{15} recorded significantly higher germination (89.75%) over the control. T_{11}, T_{12}, T_{13} and T_{14} also recorded significantly higher germination, root length, shoot length, seedling dry weight, germination rate and seedling vigor index over the control.

Puzina (2004) conducted field experiment on the potato plants were grown in a greenhouse using zinc and boron-deficient soil. The effects of seed-tuber treatment with 3 mM zinc sulfate and 8 mM boric acid on the content and ratio of phytohormones in the leaves and mature tubers, the indices of photosynthetic activity, the rate and NaF-sensitivity of respiration, and the tuber growth were studied. Zinc-sulfate treatment shifted the hormonal balance toward a substantial increase in the cytokinin content and the cytokinin/ABA ratio, as well as a decrease in the IAA/cytokinin ratio. Boric-acid treatment resulted in an increase in the IAA content and IAA/cytokinin ratio. Zinc-sulfate treatment abolished the apical dominance and increased the tuber weight due to their increased number and the number of phellem (cork) cell layers. Boric-acid treatment increased cell diameter in the tuber peri medullary zone; an increase in tuber weight plant^{-1} was related to tuber growth.

Mahesh and Sen (2005) conducted an experiment for two consecutive crop seasons to obtain information on the effect of zinc, boron and gibberellic acid on yield and net return from okra cultivation. Four levels each of zinc (0, 15, 30and 45 kg $ZnSO_4$ ha^{-1}), boron (0, 10, 20 and 30 kg borax ha^{-1}) and two levels of GA3 (0 and 50 ppm as seed soaking) were tested in randomized block design with three replications. Application of zinc at 30 kg $ZnSO_4$ ha^{-1} significantly improved various yield attributes viz., number of fruits plant^{-1}, fruit length, fruit weight, yield plant^{-1}, yield ha^{-1} (Table 1). Higher amount of zinc in the soil, i.e. 45 kg $ZnSO_4$ ha^{-1} might have toxic effect on plants, this may have decreased number of fruits, fruit length, weight, fruit yield/plant and yield/hectare.

Baloch *et al*. (2008) conducted a study using commercial foliar fertilizers, HiGrow, 50-50-25 kg ha^{-1} to study their associative effects on green chili production. HiGrow at 8 mL L^{-1} water, 68 cm height, 6.93 branches plant^{-1}, 118.86 fruits plant^{-1}, 4.19 cm fruit length, 395 g fresh chili, fruit weight plant^{-1} and 14977 kg of fresh chili ha^{-1} were produced. While decreasing the concentration to 7 ml L^{-1} water, plant height 67.86 cm, 6.53 branches plant^{-1}, fruit 117.20, fruit length 4.14 cm, fresh chili pepper 391.33 g weight plant^{-1}, fresh chili pepper 14562.33 kg ha^{-1}. Producing HiGrow with 6 ml L^{-1} water, plant height 66.46 cm, number of branches 5.80 plant^{-1}, fruit 112.36 plant^{-1}, fruit length 3.89 cm, fresh pepper 351.66 g plant^{-1} and fresh pepper 12696.33 kg results in ha^{-1}.

Angelova *et al.* (2009) in an experiment on the comparative research to determine the quantities and accumulation of lead (Pb), zinc (Zn), and cadmium (Cd) in the vegetative and reproductive organs of crops of the Solanaceae family (tomato, pepper, and aubergine) as well as to identify the possibilities of growing them on soils contaminated by heavy metals. Heavy metals have an impact on the development and productivity of the crops of the Solanaceae family. The high anthropogenic contamination impedes the normal development and fruit-bearing ability of the pepper and aubergine plants, and in the case of tomatoes, it led to an increased assimilation of heavy metals without reducing the yield and the quality of the production of tomatoes. Crops from the Solanaceae family, tomato, pepper, and aubergine plants, could be cultivated on soils having low and medium levels of contamination of heavy metals, because they do not show a tendency to accumulating Pb, Zn, and Cd in their fruits, which could still be used for consumption.

Patil *et al*. (2010) conducted an experiment to examine the effects of foliar application of micronutrients on the yield of tomato (CV. Phule Raja). The results showed that the total number of fruits (23.88) and the number of salable fruits/plants (20.34) were significantly increased when 100 ppm Fe + Zn and 50 ppm boron respectively were applied together.

Patil *et al*. (2011) reported the effect of zinc and iron levels on yield of chili. Chili crop receiving application of $ZnSO_4.7H_2O$ and $FeSO_4.7H_2O$ each at 20 kg per ha^{-1} enriched with vermicompost recorded the highest yield (1.85) tons ha^{-1}.

Barche *et al*. (2011) conducted an experiment on the effect of foliar application of micronutrients on hot pepper (Cv. Rashmi). The results showed that when boric acid + $ZnSO_4$ + $CuSO_4$ were applied, the maximum plant height (80.40 cm), branch number (34.43) and flower number (41.47) $plant^{-1}$ were recorded at 250 ppm.

Gurmani *et al.* (2012) conducted a glasshouse pot experiment, effect of soil applied Zinc (at 0, 5, 10 & 15 mg kg^{-1}) on the growth, yield and biochemical attributes was studied of two tomato cultivars; VCT-1 and Riogrande. Zinc application increased the plant growth and fruit yield in both cultivars. Maximum plant growth and fruit yield in both cultivars were achieved by the Zn application at 10 mg kg^{-1} soil. Application of 5 mg Zn kg^{-1} had lower dry matter production as well as fruit yield when compared with Zn 10 and 15 mg kg^{-1}. The percent increase of fruit yield at 5 mg Zn kg-1 was 14 and 30%, in VCT-1 and Riogrande, respectively. In the same cultivars, Zn application at 10 mg Zn kg^{-1} caused the fruit yield by 39 and 54%, while 15 mg Zn kg^{-1} enhanced by 34 and 48%, respectively. Zinc concentration in leaf, fruit and root increased with the increasing level of Zn. Zinc application at 10 and 15 mg kg^{-1} significantly increased chlorophyll, sugar, soluble protein, superoxide dismutase and catalase activity in leaf of both cultivars. The results revealed that soil application of 10 mg Zn kg^{-1} soil have a positive effect on yield, biochemical attributes and enzymatic activities of both the tomato cultivars.

Nawaz *et al.* (2012) experiment on interactive effects of nitrogen (N), phosphorus (P) and zinc (Zn) on growth and yield of tomato. Four levels of nitrogen (0, 100, 150 and 200 kg ha^{-1}), four levels of phosphorus (0, 60, 80 and 100 kg/ ha) and three levels of zinc (0, 5 and 10 ppm) were applied. The results pertaining to various growth and yield parameters showed that early flowerings were observed when plots received phosphorus at 100 kg ha^{-1} and zinc at 10 ppm without nitrogen. The minimum disease incidence (3.67%) was recorded in plots applied with phosphorus at 100 kg ha^{-1} and zinc at 10 ppm without nitrogen. Maximum number of fruit $plant^{-1}$ (41.67) was observed when plots received nitrogen at 150 kg ha^{-1}, phosphorus at 100 kg ha^{-1} and zinc at 10 ppm. Total yield (28.43 t ha^{-1}) was 100% increased as compared to control (13.44 t ha^{-1}) when plots received nitrogen at 150 kg ha^{-1}, phosphorus at 100 kg ha^{-1} and zinc at 10 ppm.

Datir *et al*. (2012) conducted a pot experiment to determine the effects of foliar application of organically chelated micronutrients on growth and yield in chili (*Capsicum annum* L.). The micronutrients like iron, zinc, copper and manganese were organically chelated with seed amino acids. Forty day's old seedlings of chili were transplanted in the pots. The experimental plants were sprayed with three doses (0.5, 1.5 and 2.0%) of organically chelated micronutrients along with unchelated micronutrients, amino acid solution and untreated control plants on 15th and 30th days after transplantation. The results based on two years mean revealed that out of five different treatments, the application of amino acid-micronutrient chelate at the concentration of 1.5 and 2.0% resulted in maximum plant height, number of primary branches $plant^{-1}$, higher leaf area $plant^{-1}$, fruits $plant^{-1}$ and more total yield $plant^{-1}$.

Shil *et al*. (2013) conducted a study on Chili (cv. Bogra local) on gray terraced soil under AEZ-25 (Level Barind Tract) at the Spice Research Center. The aim was to evaluate the chili pepper response to zinc in order to find the optimal dosage of zinc to maximize yield. Four doses of zinc (0, 1.5, 3.0, and 4.5 kg ha^{-1}) were used in the study. The effect of zinc was pronounced for dry pepper yield and ripe pepper/plant weight.

However, regression analysis indicated that the economically optimal zinc dosage was 3.91 kg ha^{-1}. Therefore, it is recommended to combine the (Zn 3.91 kg ha^{-1}) package with the aforementioned uniform dose to maximize pepper yield in the study area.

Perez *et al.* (2017) was investigating on Andean potato (*Solanum tuberosum* L., Andigenum) which is biofortified with iron (Fe) and zinc (Zn) fertilizers. The rate of increase of tuber Zn following Zn fertilization was similar across cultivars. High rates of foliar Zn application reached a 2.51-fold tuber Zn increase, and high rates of soil Zn application a 1.91-fold tuber Zn increase. The results confirmed the proof of concept that Andean potato cultivars can be agronomically Zn-biofortified with foliar and soil applied Zn fertilizers.

Ilyas *et al.* (2019) carried out a field experiment to investigate the effect of boron and zinc on the growth and yield of tomato. Three levels of boron (viz., 0, 1 and 2kg H_3B0_3 ha^{-1}) and zinc (viz., 0, 1 and 2kg $ZnS0_4$ ha^{-1}) were applied for each experiment. Results revealed that boron had significant effect on all yield attributes and yield of tomato. Application of 2kg H_3B0_3/ha produced the highest tomato yield (79.2-ton ha^{-1}) as well as maximum yield of tomato was obtained from 2kg $ZnS0_4$ ha^{-1}.

Ali *et al.* (2019) was carried out experiment at a private farm with an objective to evaluate the performance of manure, organic poultry residuals, dry yeast extract and zinc sulfate on growth and yield of potato. The experiment was arranged in a split-plot within a randomized complete block design keeping three poultry litter doses (0, 1.5 and 3 Mt ha^{-1}) as the main plot treatments and five dry yeast extract doses (0, 2, 4, 6 and 8 g/l) and two zinc sulfate ($ZnSO_4$) doses (200 and 400 mg/l) as the sub-plot treatments. The best response for higher total and marketable yields was recorded with the application of 3 Mt ha^{-1} poultry litter in combination with 200 g/l $ZnSO_4$.

Modi *et al.* (2019) carried out an experiment on effect of zinc and boron on yield of brinjal. The highest plant height, average fruit weight, number of fruits $plant^{-1}$ and fruit yield of brinjal was recorded with the soil application of zinc and boron which was superior over the foliar spray. The gross return, net return and benefit cost ratio recorded was also maximum in improved practices consisting soil application of zinc and boron as compared farmer's practices.

Kanwar *et al.* (2019) conducted field experiment to investigate the response of zinc application on quality of potato tubers, field experiments were carried out during winter season. The experiment was laid out in randomized block design with five treatments replicated four times. The results indicated that dry matter per cent (19.9 %), starch (17.5%), specific gravity (1.04%) and available zinc content (52.64 ppm) in potato tubers were recorded maximum in treatment T_5 (Recommended dose of fertilizer of NPK + 6.0 kg zinc at the time of planting). Based on present investigation, it can be concluded that basal application of zinc at 6.0 kg ha^{-1} along with recommended dose of fertilizer improved potato tuber quality under tarai region of Uttarakhand.

Shahid *et al* (2020) conducted an experiment on zinc-solubilization potential of fluorescent pseudomonads to observe their role in growth promotion of tomato. Nine strains of Pseudomonas spp. were screened to solubilize ZnO, $ZnSO_4$ and $ZnCO_3$ on tris-minimal agar plates. *P. chlororaphis* strain RP-4 solubilized $ZnCO_3$ whereas, *P. aurantiaca* strains GS-4 and Type strain (NCIB 10068T) solubilized $ZnCO_3$ and ZnO, only. Moreover, cotton isolate *P. aurantiaca* ARS-38, solubilized ZnO, however, rest of the strains could not solubilize ZnCO3 or ZnO. All bacterial strains were analyzed for their growth enhancement potential, at pot-scale plant experiments and effect was observed on growth parameters. Plant experiments were set-up in RCBD, conducted in triplicate and harvested after four weeks. Maximum fresh weights of shoots and roots were noted for the plants inoculated with *P. aurantiaca* PB-St2 (non Zn-solubilizer), however, maximum dry root weights were recorded for the Zn-solubilizer strain RP-4 (*P. chlororaphis*) inoculated plants. Likewise, substantial increase in root and shoot lengths and area were observed for the Zn-solubilizer strains GS-4, and ARS-38 (*P. aurantiaca*) inoculated plants in comparison of un-inoculated controls. These findings indicate the potential of Zn biofertilizer strains of *Pseudomonas spp*. in increasing bioavailability of zinc to plants for sustainable agriculture.

Bhuvaneshwari *et al.* (2020) studied the effects due to the application of humic acid and zinc sulphate on the yield characters of brinjal crop to determine the response of brinjal to soil application of humic acid and zinc sulphate at different concentrations. Humic acid(HA) and zinc sulphate are applied three weeks after planting. Soil application of both humic acid and zinc sulphate positively affected the yield characters viz., number of fruits $plant^{-1}$, fruit length, single fruit weight, fruit girth and total fruit yield of brinjal crop when compared to control. The highest yield characters were observed with humic acid at 30 kg ha^{-1} and zinc sulphate at 50 kg ha^{-1}. This treatment rated efficient in increasing the yield comparing to control. The highest fruit yield was found to be 22.64 t ha^{-1} and control (10.87 t ha^{-1}). Hence the study shows that the soil application of HA@ 30 kg ha^{-1} + $ZnsO_4$ @ 50 kg ha^{-1} concentration could be successfully used to obtain better yield in brinjal.

Al-Fadhly *et al.* (2020) conducted a field experiment to study the effect of foliar application of zinc and manganese at different stage of potato growth on some quality characteristics of potato tuber (*Solanum tuberosum* L.) fertilized with organic matter in silt clay loam texture soil. A randomized complete block design RCBD was used with three replicates including two factors the first factor is foliar application includes the treatment (T_0 water spray only, T_1 spraying with zinc at 60 mg l^{-1} , T_2 spraying with manganese at 30 mg L^{-1} and T_3 spraying with zinc at 60 mg L^{-1} + Spraying with manganese at 30 mg L^{-1}) and the second factor is the stage of potato growth includes the treatments (F_1 spraying in the vegetative growth, F_2 spraying in tuber initiation and F_3 spraying at tuber bulking). Addition of organic manure (mixture of equal amounts of cows, sheep and chicken) at 50-ton ha^{-1} for all treatments at 10 days before planting. The results showed the significant effect of zinc and manganese spraying at different stage and their interactions, the treatment T_3F_1 has recorded the highest dry matter for tubers at 16.17% with an increase of 24.57% compared to the treatment T_0 F_1 and recorded the highest Starch percentage at 10.40% with an increase of 42.08% compared to the treatment T_0F_2.

Prasad *et al.* (2021) conducted an experiment with one green house to assess the impact of zinc on tomato. Results suggested that all parameters were significantly improved in both deficient and sufficient soils upon the addition of external zinc along with RDF. The treatment T_9 in high zinc soils significantly improved the quality parameters like TSS (6.00º Brix), titratable acidity (0.39%), Vitamin C (53.71 mg 100 g^{-1}), lycopene (13.24 mg 100 g^{-1}) and shelf life (24 days) when compared with other treatments. The zinc uptake and zinc use efficiency was recorded higher in T_9 as 238.91 g ha^{-1} and 2.47% which is more than that of RDF. But in low zinc soils treatment T_{10} significantly improved the quality parameters like TSS (5.80º Brix) which is on par with T_9 (5.90º Brix), titratable acidity (0.47%), Vitamin C (55.24 mg 100 g^{-1}), lycopene (13.30 mg 100 g^{-1}) and shelf life (23 days).The zinc uptake and zinc use efficiency was recorded higher in T_{10} as 291.53 g ha^{-1} and 2.64% which is more than that of RDF.

Johura *et al.* (2021) a pot experiment was carried out the effect of Zn and Cu on the growth and yield of tomato. There were six doses of fertilizer in experiment, viz., T_0 = Control, T_1 = Recommended dose of fertilizer ($N_{160}P_{50}K_{100}S_{20}$) kg ha^{-1}, T_2 =75% NPKS from inorganic fertilizer and 25% NPKS from cow dung, T3= Recommended dose of fertilizer with Zn and Cu ($N_{160}P_{50}K_{100}S_{20}$ + Zn_4 +Cu_4) kg ha^{-1}, T4= Recommended dose of fertilizer with Cu ($N_{160}P_{50}K_{100}S_{20}$ + Cu_4) kg ha^{-1}, T5= Recommended dose of fertilizer with Zn ($N_{160}P_{50}K_{100}S_{20}$+ Zn_4) kg ha^{-1} were used to conduct this experiment The higher number of fruits $plant^{-1}$ was observed in T_3 treatment. The zinc and copper of tomato significantly influenced on the yield of fruits $plant^{-1}$. The maximum yield of fruits $plant^{-1}$ (347.60 g) was obtained from T_3 treatment and the minimum yield of fruits $plant^{-1}$ (183.73 g) was obtained from control treatment.

Chapter III

Materials & Methods

Chapter III

MATERIALS AND METHODS

This chapter includes a brief description of the experimental site, experimental period, climatic condition, crop or planting materials, land preparation, experimental design and layout, crop growing procedure, treatments, intercultural operations, data collection, preparation and chemical analysis of soil along with statistical analysis.

3.1 Location of the experiment field

The experiment was conducted at Agronomy field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during the period From November, 2021 to April, 2022. The location of the experimental site was at 23°75′ N latitude and 90°34′ E longitudes with an elevation of 8.45 meter from sea level.

3.2 Climate of the experimental area

The experimental area is characterized by subtropical rainfall during the month of November to April (Anon., 1988) and scattered rainfall during the rest of the year. Information regarding average monthly temperature as recorded by Bangladesh Meteorological Department (climate division) during the period of study has been presented in (Appendix II).

3.3. Soil of the experimental field

Soil of the experimented field belongs to the Tejgaon series under the Agro Ecological Zone, AEZ-28 (Madhupur Tract). In this series soil types are in general is shallow deep red brown terrace soils. A composite sample was made by collecting soil from several spots of the field at a depth of 0-15 cm before the initiation of the experiment. The collected soil was air-dried, ground and passed through 2 mm sieve and analyzed for some important physical and chemical parameters. Soil pH was determined by glass-electrode pH meter method (Jackson, 1958) and wet oxidation method was used for determining soil organic carbon (Walkley and Black, 1934). The available S was determined by sodium bicarbonate extraction (Olsen *et al.*, 1954) and available Ca determined by calcium chloride extraction method (Houba *et al.*, 2000). The morphological characteristics of the experimental field and initial physical and chemical characteristics of the soil are presented in Table 3.1, 3.2 and 3.3 respectively.

Table 3.1. Morphological characteristics of experimental field

Morphological features	Characteristics
Location	Agronomy farm, SAU, Dhaka
AEZ No. and name	AEZ-28, Madhupur Tract
General soil type	Shallow Red Brown Terrace Soil
Soil series	Tejgaon
Topography	Fairly leveled
Depth of inundation	Above flood level
Drainage condition	Well drained
Land type	High land

Table 3.2. Physical properties of the initial soil of the experimental field

Physical properties	Values
%Sand (2-0.02 mm)	30%
%Silt (0.02-0.002 mm)	40%
%Clay (<0.002 mm)	30%
Textural class	Clay loam
Particle density	2.57 g cc^{-1}

Table 3.3 Chemical characteristics of the initial soil of the experimental field

Chemical properties	Values
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.06
Available P(ppm)	20.0
Available S(ppm)	14.7

3.4 Plant material

Chili (cv. BARI Morich 4) was used as experimental crop. The seeds were collected from Spice Research Centre, Bogura.

3.5 Treatments

The experiment consisted of two factors:

Factor A: Sulphur – Three levels of Sulphur denoted as S

1. S_0 = 0 kg ha^{-1}
2. S_1 = 20 kg ha^{-1}
3. S_2 = 30 kg ha^{-1}

*Gypsum was used as source of Sulphur.

Factor B: Zinc – Three levels of Zinc denoted as Zn

1. Zn_0 = 0 kg ha^{-1}
2. Zn_1 = 2 kg ha^{-1}
3. Zn_2 = 4 kg ha^{-1}

** Zinc sulphate monohydrate ($ZnSO_4.H_2O$) was used as source of zinc.

Treatment Combinations of S and Zn – 9 (3 × 3) treatment combinations such as S_0Zn_0, S_0Zn_1, S_0Zn_2, S_1Zn_0, S_1Zn_1, S_1Zn_2, S_2Zn_0, S_2Zn_1, S_2Zn_2.

3.6 Design and layout of the experiment

The two factors experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The total area of the experimental plot was 20.75m×11m = 228.5 m^2 which was divided into three equal blocks. Each block was divided into 9 plots where 9 treatments combination were allotted at random. There were 27 unit plots altogether in the experiment. The size of each plot was 3.0 m × 1.75 m. The distance maintained between two blocks and two plots were 0.5 m, respectively. Seeds were sown in the plot with maintaining distance between row to row and plant to plant was 50 cm and 50 cm, respectively. The layout of the experiment is shown in Figure 1.

3.7 Seedbed preparation

Seedbed was prepared on November 2021 for raising seedlings of green chili and the size of the seedbed was 3 m × 1 m. For making seedbed, the soil was well ploughed. Weeds, stubbles and dead roots were removed from the seedbed. Cow dung was applied to the prepared seedbed @ 10 t ha^{-1}. The soil was treated by Sevin 50WP @ 5 kg ha^{-1} to protect the young plants from the attack of ants and cutworms. Seeds were treated by Vitavex-200 @ 5 g kg^{-1} seeds to protect some seed borne diseases such as leaf spot, blight, anthracnose, etc.

3.8 Seed sowing

Seeds were sown on mid November 2021 in the seedbed. Sowing was done in lines spaced at 5 cm distance. Seeds were sown at a depth of 2 cm and covered with a fine layer of soil followed by light watering by watering can. Thereafter, the beds were covered with polythene to maintain required temperature and moisture.

3.9 Raising of seedlings

Light watering and weeding were done several times as per needed. No chemical fertilizers were applied for rising of seedlings. Seedlings were not attacked by any kind of insect or disease. Healthy and 30 days old seedlings were transplanted into the experimental field on December 2021.

3.10 Preparation of the field

The plot selected for conducting the experiment was opened in the first week of November 2021, with a power tiller and left exposed to the sun for a week to kill soil borne pathogens and soil inhabitant insects. After one week the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain until good tilth. The land was leveled, corners were shaped and the clods were broken into pieces. Weeds, crop residues and stables were removed from the field. The basal dose of manure and fertilizers were applied at the finally ploughing. The plots were prepared according to design and layout of the experiment. The soil of the plot was treated by Sevin 50WP @ 5 kg ha^{-1} to protect the young plants from the attack of ants and cutworm.

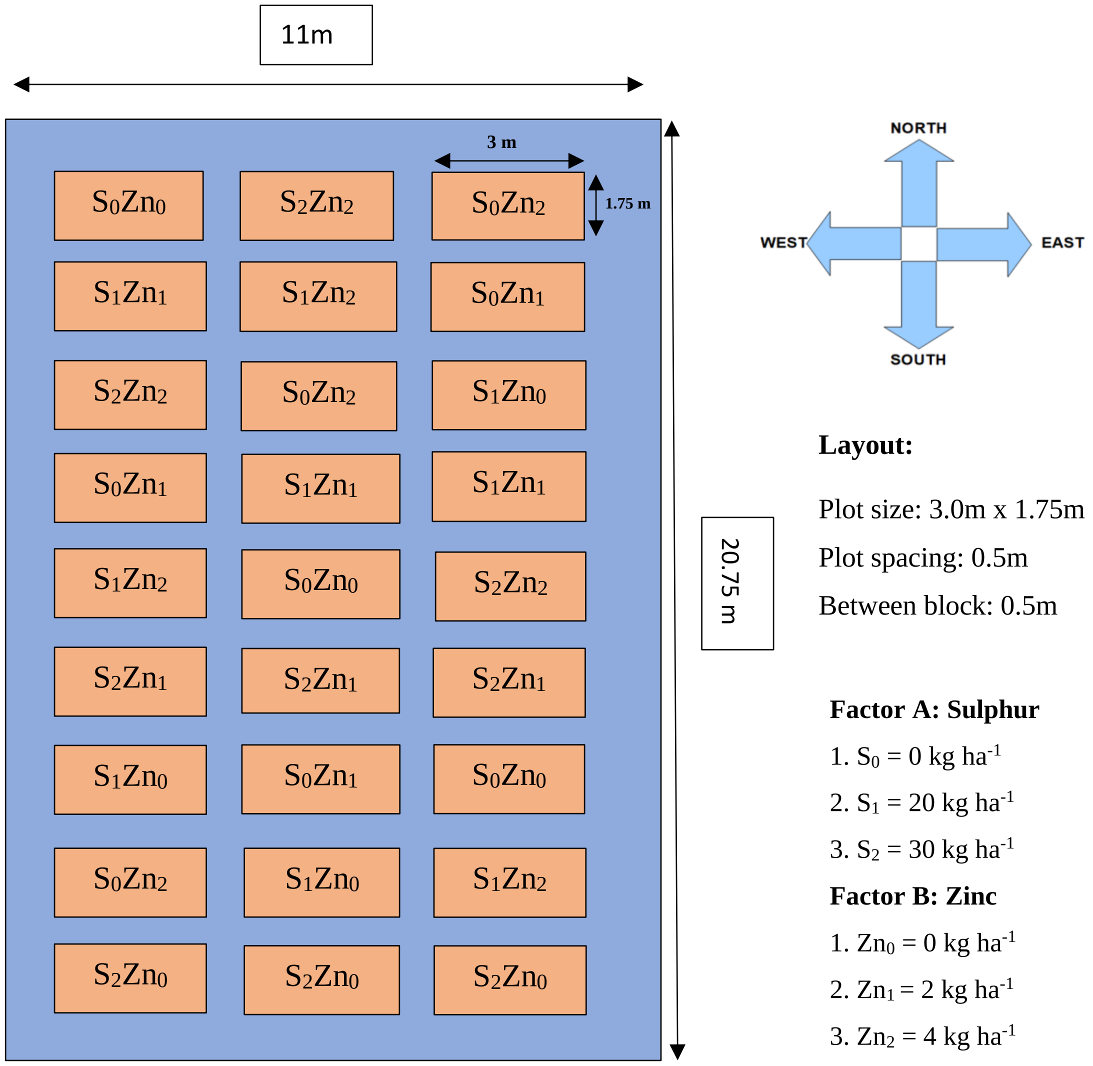

Fig 3.1: Layout of the experiment plot

3.11 Application of manure and fertilizers

The N, P, K, S, Zn and B nutrients were applied through Urea, Triple superphosphate (TSP), Muriate of Potash (MoP), Gypsum, Zinc sulphate monohydrate ($ZnSO_4.H_2O$) and Boric acid respectively. Sulphur (S) and Zinc (Zn) were applied as per treatment where rest of the nutrients were applied according to Fertilizer Recommendation Guide, 2018. One third of whole amount of Urea, full amount of Cowdung as manure, TSP, MoP, Gypsum, $ZnSO_4.H_2O$ and Boric acid were applied at the time of final land preparation. The remaining Urea was top dressed in two equal installments - at 20 days after transplanting (DAT) and 50 DAT respectively. Name and doses of fertilizers are shown in Table 3.4 .

Table 3.4. Doses and method of application of fertilizers in green chili field

Nutrients	Manure and fertilizer	Doses (ha^{-1})
---------	Cowdung	10 t
N	Urea	250 kg
P	TSP	200 kg
K	MoP	160 kg
B	Boric acid	12 kg
S	Gypsum	As per treatment
Zn	$ZnSO_4.H_2O$	As per treatment

3.12 Transplanting of seedlings

Healthy and uniform 20 days old chili seedlings were transplanted in the experimental plots on 4th December, 2021. The seedlings were uprooted carefully from the seed bed to avoid damage to the root system. To minimize the damage to the roots of seedlings, the seed beds were watered one hour before uprooting the seedlings. Transplanting was done in the afternoon. The seedlings were watered immediately after transplanting. Seedlings were transplanted in the plot and distance maintained between row to row and plant to plant were 50 cm and 60 cm, respectively and total 15 plants were accommodated in each plot. The young transplants were shaded by banana leaf sheath during day time to protect them from scorching sunshine up to 7 days until they were set in the soil. They (transplants) were kept open at night to allow them receiving dew. A number of seedlings were also planted in the border of the experimental plots for gap filling.

3.13 Intercultural operation

After raising seedlings, various intercultural operations, such as gap filling, weeding, earthing up, irrigation pest and disease control etc. were accomplished for better growth and development of the chili seedlings.

3.13.1 Gap filling

The transplanted seedlings in the experimental plot were kept under careful observation. Very few seedlings were damaged after transplanting and such seedling were replaced by new seedlings from the same stock. Planted earlier on the border of the experimental plots same as planting time treatment. Those seedlings were transplanted with a big mass of soil with roots to minimize transplanting stock. Replacement was done with healthy seedling having a boll of earth. The transplants were given shading and watering for 7 days for their proper establishment.

3.13.2 Weeding

The crop field was weeded out thrice at 25, 55 and 75 DAT and also done whenever necessary to keep the crop free from weeds.

3.13.3 Irrigation

Number of irrigation was given throughout the growing period by garden pipe, watering cane. The first irrigation was given immediate after the 25 days of transplantation where as other were applied when and when required depending upon the condition of soil.

3.13.4 Plant protection

Chili plants infected with anthracnose and die back were controlled by spraying Cupravit (3g L^{-1}) at 15 days interval. Few plants found to be infected by bacterial wilt were uprooted. The established plants were affected by aphids. Diazinon 60EC (15cc/10 L) was applied against aphids and other insects.

3.14 Harvesting

Fruits were harvested at 6 to 7 days intervals during early ripe stage when they attained marketable size. Harvesting was started from mid-March, 2021 and was continued up to mid-April, 2022.

3.15 Data collection

Five plants were selected randomly from each plot for data collection in such a way that the border effect could be avoided for the highest precision. Data on the following parameters were recorded from the sample plants during the course of experiment.

3.15.1 Plant height (cm)

The plant height was measured in centimeters from the base of plant to the terminal growth point of main stem on tagged plants was recorded at 20 days interval starting from 40 days of planting up to 80 days to observe the growth rate of plants. The average height was computed and expressed in centimeters.

3.15.2 Number of leaves per plant

The number of leaves plant^{-1} was measured with a meter scale from five selected plants at 40, 60 and 80 days after transplanting on tagged plants. The average of leaves number from five plants were computed and expressed in average number of leaves plant^{-1}.

3.15.3 Number of branches per plant

The number of primary branches plant^{-1} was manually counted at 40, 60, 80 days after transplanting from tagged plants. The average of primary branches from five plants were computed and expressed in average number of primary branch plant^{-1}.

3.15.4 Numbers of flowers per plant

Flowers were counted at the flowering stage. Five plants were selected randomly from each plot. Number of flowers were counted and averaged.

3.15.5 Number of fruits per plant

Five plants were selected randomly from each plot. At first, number of fruits plant^{-1} were counted and averaged for each plot. Then it was multiplied with number of fruits plant^{-1} and averaged.

3.15.6 Length of fruit (cm)

The length of fruit was measured with a meter scale from the neck of the fruit to the bottom of fruits from each plot and their average was taken and expressed in cm.

3.15.7 Diameter of fruit (cm)

Diameter of fruit was measured at the middle portion of fruit from each plot with a digital calipers-515 (DC-515) and average was taken and expressed in cm.

3.15.8 Individual fruit weight (g)

The weight of individual fruit was measured with a digital weighting machine from fruits from each selected plots and their average fruit weight was taken and expressed in gram (g). Ten fruits weight were taken randomly from different plot and then average was calculated.

3.15.9 Average fruit weight per plant (g)

The average weight of fruit plant^{-1} was measured with a digital weighing machine from fruits from each selected plants and their average was taken and expressed in gram (g). Five plants were selected in each plot and fruit weights were recorded and then average fruit weight plant^{-1} was calculated.

3.15.10 Yield of fruits ha^{-1}

It was measured by the following formula:

$$\text{Fruit yield (t ha}^{-1}\text{)} = \frac{\textbf{\textit{Fruit yield per plot}}(\textbf{\textit{kg}})\ \textbf{\textit{x}}\ \mathbf{10000}}{\textbf{\textit{Area of plot in square meter x}}\ \mathbf{1000}}$$

3.15.11 Statistical analysis

The recorded data on various parameters were statistically analyzed using MSTAT-C statistical package program. The mean for all the treatments was calculated and analysis of variance for all the characters were performed by F Difference between treatment means were determined by Duncan`s Multiple Range Test (DMRT) according to Gomez and Gomez, (1984) at 5% level of significance.

Chapter IV

Results and Discussion

Chapter IV

RESULTS AND DISCUSSION

The results obtained with different levels of Sulphur (S) and Zinc (Zn), their combinations are presented and discussed in this chapter. Data about growth parameters, yield contributing characters and yield of chili have been presented in both Tables and Figures and analyzes of variance and corresponding degrees of freedom have been shown in Appendix.

4.1 Effects of S and Zn on the growth parameter of chili

4.1.1 Plant height (cm)

The application of different levels of sulphur (S) and zinc (Zn) fertilizer had significant influence on chili (BARI Morich 4) plant height at different days after transplanting (DAT) (Appendix V).

Effect of S on plant height of chili

Sulphur application to green chili variety (BARI Morich 4) showed significant variation for plant height at 40, 60, 80 days after transplanting (DAT) (Figure 4.1). Results revealed that the tallest plant (33.33, 45.92, 66.12 cm at 40, 60, 80 DAT respectively) was recorded from S_1 (20 kg S ha^{-1}) treatment. The shortest plant (29.14, 38.90, 54.39 cm at 40, 60, 80 DAT respectively) was found from control treatment, S_0 (0 kg S ha^{-1}). This may be caused by an improvement in growth characteristics and the recognized role of optimum level of sulphur in cell division, the photosynthetic process, and chlorophyll formation. Muthanna *et al.* (2017) and Saeed and Ahmad (2009) also found similar result which supported the present study. Sulphur is required for the synthesis of important essential amino acids by increasing allyl propyl disulphide alkaloid (43% S). This might explained the importance of S in improving yield and quality by influencing the S containing amino acids, which are the building blocks of proteins, and along with starch are responsible for formation of fruits (Arora and Luchra, 1970). Adequate sulphur availability ensures sufficient protein synthesis, which is necessary for cell division, elongation, and overall plant growth. Optimal protein synthesis indirectly contributes to plant height (Gopal *et al.*, 2003).

Effect of Zn on plant height of chili

Plant height of green chili variety (BARI Morich 4) varied significantly for application of Zn at 40, 60, 80 DAT (Figure 4.2). Results indicated that the tallest plant (33.62, 45.95, 66.06 cm at 40, 60, 80 DAT respectively) was obtained from Zn_2 (4.0 kg Zn ha^{-1}). The shortest plant (29.51, 39.75, 56.54 cm at 40, 60, 80 DAT and respectively) was found from control treatment, Zn_0 (0 kg Zn ha^{-1}) which was statistically different from all other Zn application effect. Improvement in growth characters as a result of application of micronutrients might be due to the enhanced photosynthetic and other metabolic activity which leads to an increase in various plant metabolites responsible for cell division and elongation as opined by Hatwar *et al.* (2003) which leads to produced tallest plant. Datir *et al.* (2012) reported that micronutrients like iron, zinc, copper and manganese were organically chelated with seed amino acids and the application of amino acid-micronutrient chelate at the concentration of 1.5 and 2.0% resulted in maximum plant height. Similar results were also found by Jamre *et al.* (2010), Rohidas *et al.* (2010) and Barche *et al.* (2011). Zinc is involved in auxin synthesis and regulation, which is a plant hormone responsible for cell elongation and growth. Adequate zinc levels contribute to proper auxin production and transport, promoting vertical growth and increasing plant height. Zinc exerts a great influence on basic plant life process such as nitrogen metabolism, photosynthesis, protein quality and resistance to a biotic and biotic resistance in plants (Potarzycki, and Grzebisz, 2009).

Interactive effect of sulphur and zinc on plant height

Significant variation was observed due to the interaction effect of S and Zn in terms of plant height of chili at 40, 60, 80 DAT (Table 4.1.1). Results signified that the tallest plant 35.39 cm, 50.76 cm and 74.83 cm observed at 40, 60 and 80 DAT respectively from S_1Zn_2. Statistically similar results observed from Sn_2Zn_2 at 60 and DAT. On the other hand, shortest plant height 25.81 cm, 36.76 cm and 51.51 cm at 40, 60 and 80 DAT recorded from S_0Zn_0 treatment combination. The response of plants to one nutrient increases with an increase in the level of the other nutrient, the interaction is positive and the nutrients synergistic. Due to this positive and synergistic interaction between sulphur and zinc different growth and yield characteristics including plant height, leaf and shoot growth, other macro and micro nutrient availability to the plants, yield and yield attributes improve significantly of chili plant. Baudh and Prasad (2012) also reported a positive Zn×S interaction in growth characters and yield attributes.

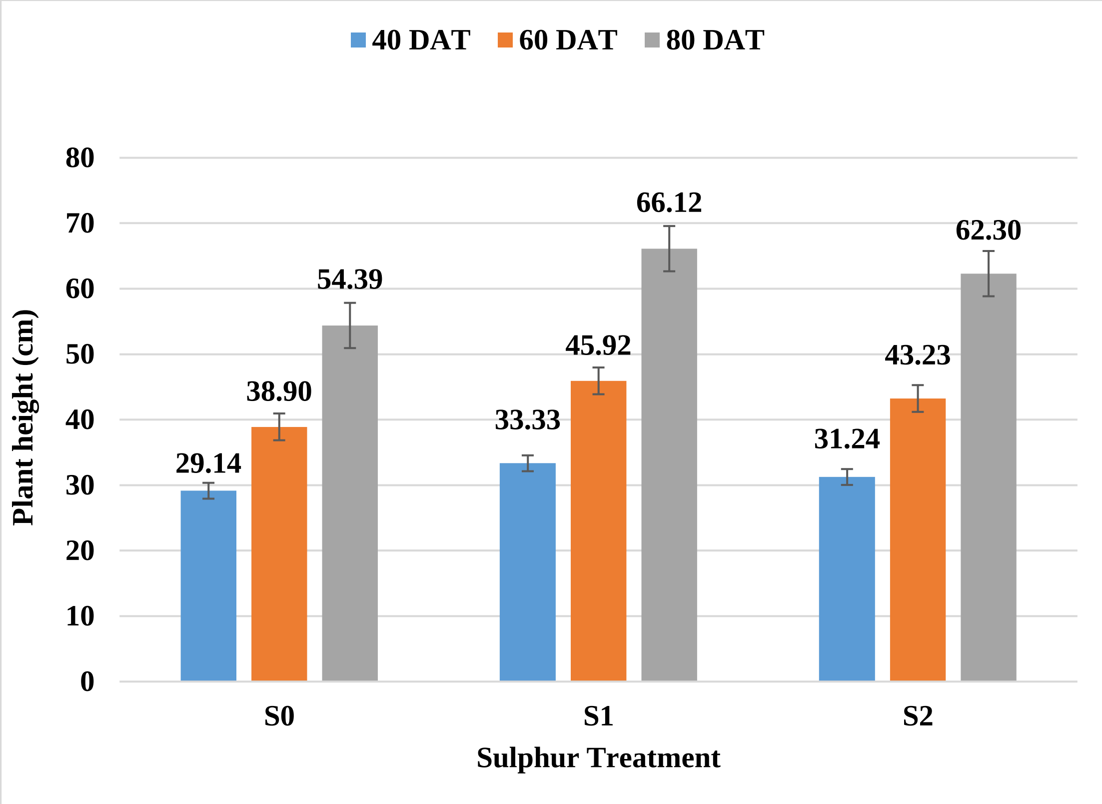

Figure 4.1: Effect of sulphur on the plant height of chili at different DAT

Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1}

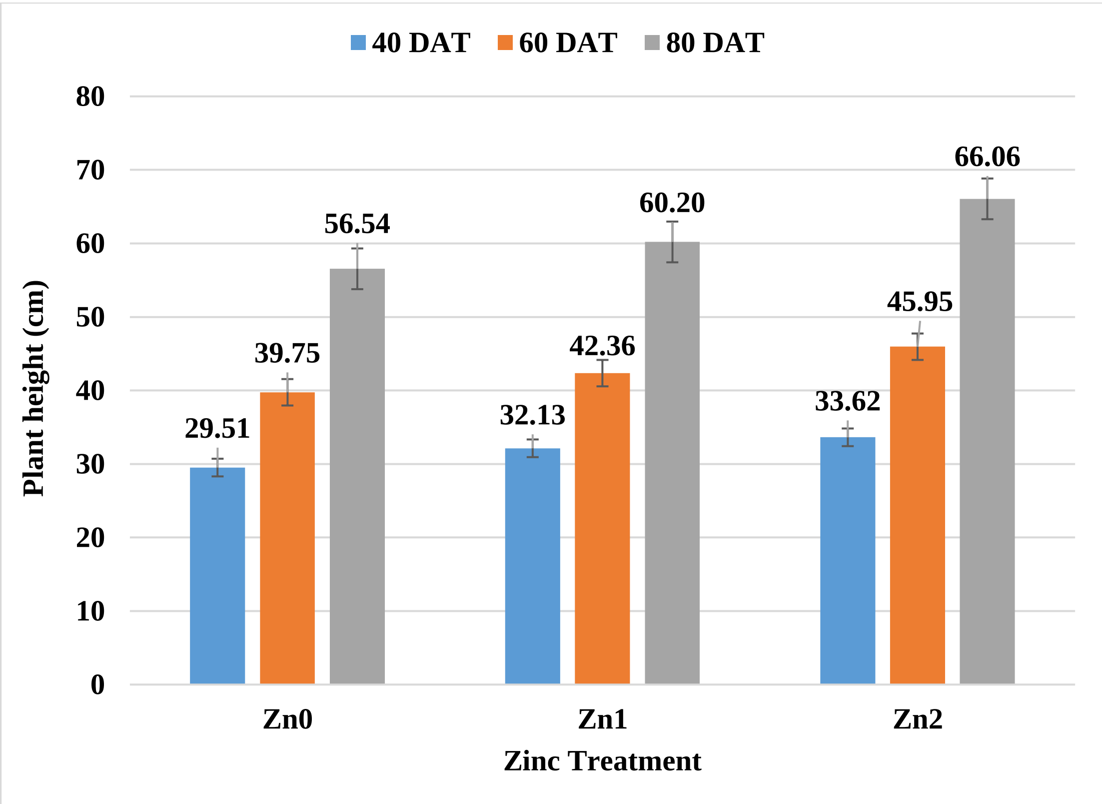

Figure 4.2: Effect of zinc on the plant height of chili at different DAT

Here, Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

Table 4.1.1: Combined effects of S and Zn on plant height of chili at different 40, 60 and 80 DAT

Treatment	Plant height (cm)		
	40DAT	60DAT	80DAT
S_0Zn_0	**25.81 i**	**36.76 hi**	**51.51 i**
S_0Zn_1	29.08 h	37.38 gh	54.60 h
S_0Zn_2	32.95 de	41.40 e	59.43 ef
S_1Zn_0	33.04 cde	43.77 de	61.91 d
S_1Zn_1	33.30 cd	46.54 c	64.09 bcd
S_1Zn_2	**35.39 a**	**50.76 a**	**74.83 a**
S_2Zn_0	29.69 gh	38.54 fgh	57.05 g
S_2Zn_1	32.53 def	40.47 ef	58.70 efg
S_2Zn_2	34.02 ab	48.55 ab	66.30 bc
Level of significance	*	*	*
SE (±)	1.04	2.38	1.58
CV (%)	5.98	9.15	4.52

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability. Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1} ; SE (±) = Standard Error ; CV (%) = Co–efficient of variation

4.1.2 Number of leaves per plant

The application of different levels of sulphur (S) and zinc (Zn) fertilizer and their interaction activity had significant influence on the number of leaves plant^{-1} of chili (BARI Morich 4) during the present experiment (Appendix VI). The following results were observed at different days after transplanting (DAT).

Effect of S on number of leaves per plant

Number of leaves plant^{-1} of green chili showed statistically significant differences due to application of different S doses(Figure 4.3). Results showed that maximum number of leaves plant^{-1} (46.06, 85.66, 96.13 at 40, 60, 80 DAT respectively) was recorded from S_1 (20 kg S ha^{-1}) while the minimum number of leaves plant^{-1} (35.37, 68.44 and 74.22 at 40, 60, 80 DAT respectively) was recorded from control treatment, S_0 (0 kg S ha^{-1}). Maniruzzaman *et al.* (2016) also observed that the number of leaves plant^{-1} was higher with the increased S rates up to 30 kg ha^{-1}. This finding is also similar with the previous reports for the increased leaf number of chili with S fertilization (Islam *et al*., 2013; Lalitha and Gopala 2004).

Effect of Zn on number of leaves per plant

Number of leaves plant^{-1} of green chili differed significantly due to the effect of Zn application as micronutrient at 40, 60, 80 DAT (Figure 4.4). It was found that the highest number of leaves plant^{-1} (45.05, 82.19, 92.61 at 40, 60, 80 DAT respectively) was found from Zn_2 (4.0 kg Zn ha^{-1}) while the minimum number of leaves plant^{-1}(36.29, 72.51, 78.61 at 40, 60, 80 DAT respectively) was found from control treatment, Zn_0 (0 kg Zn ha^{-1}) (Table 4.1.2). Similar result was also observed by Sindhu and Tiwari (1989). Zinc also plays a significant role in plant resistance against disease, photosynthesis, cell membrane integrity, protein synthesis, pollen formation and enhance the level of antioxidant enzymes and chlorophyll within plant tissues (Azhar *et al.*, 2015).

Combined effect of S and Zn application on number of leaves per plant

S and Zn application to green chili plants showed significant variation due to the interaction effect on number of leaves plant^{-1} at 40, 60, 80 DAT respectively (Table 4.1.2). Results demonstrated that the maximum number of leaves plant^{-1} (53.37, 92.34, 101.32 at 40, 60, 80 DAT respectively) was recorded from S_1Zn_2 which was closely followed by S_2Zn_2 at 60 and 80 DAT, whereas the minimum number of leaves plant^{-1} (32.24, 64.52, 68.57 at 40, 60, 80 DAT respectively) was observed from S_0Zn_0 followed by S_0Zn_1 at all growth stages.

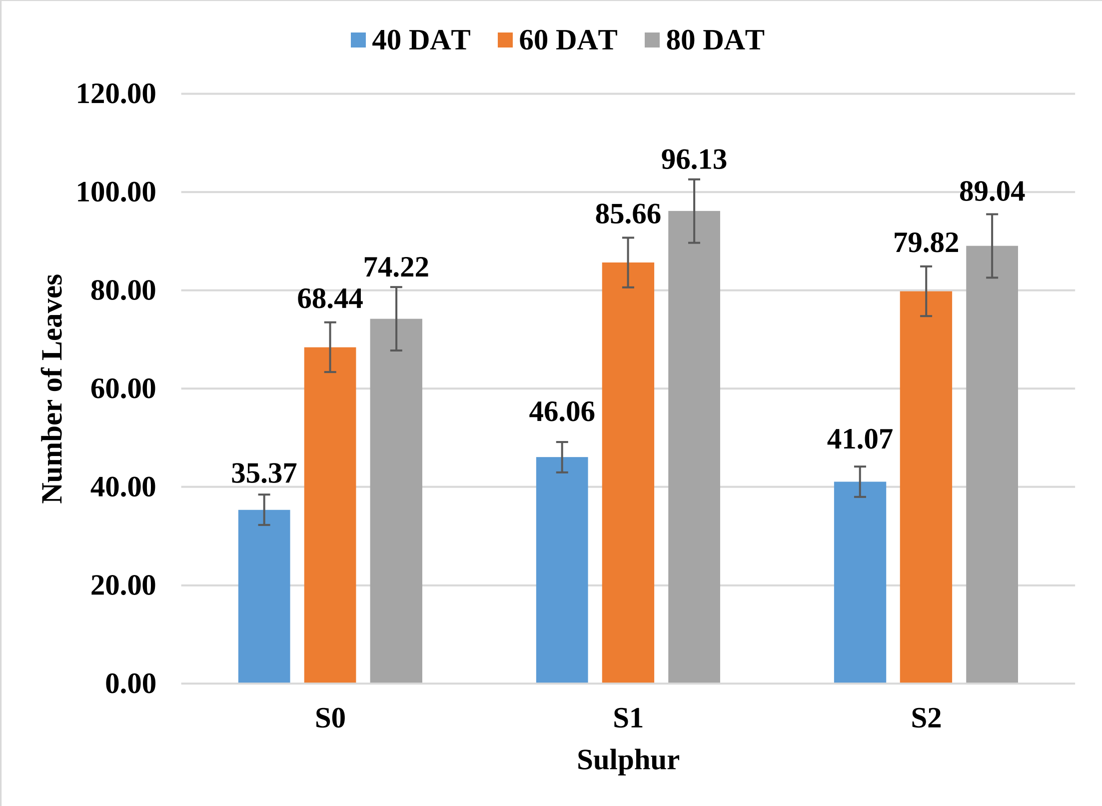

Figure 4.3: Effect of sulphur on the number of leaves plant^{-1} at different DAT

Here, S_0 = 0 kg ha^{-1}, S_1 = 20 kg ha^{-1}, S_2 = 30 kg ha^{-1}

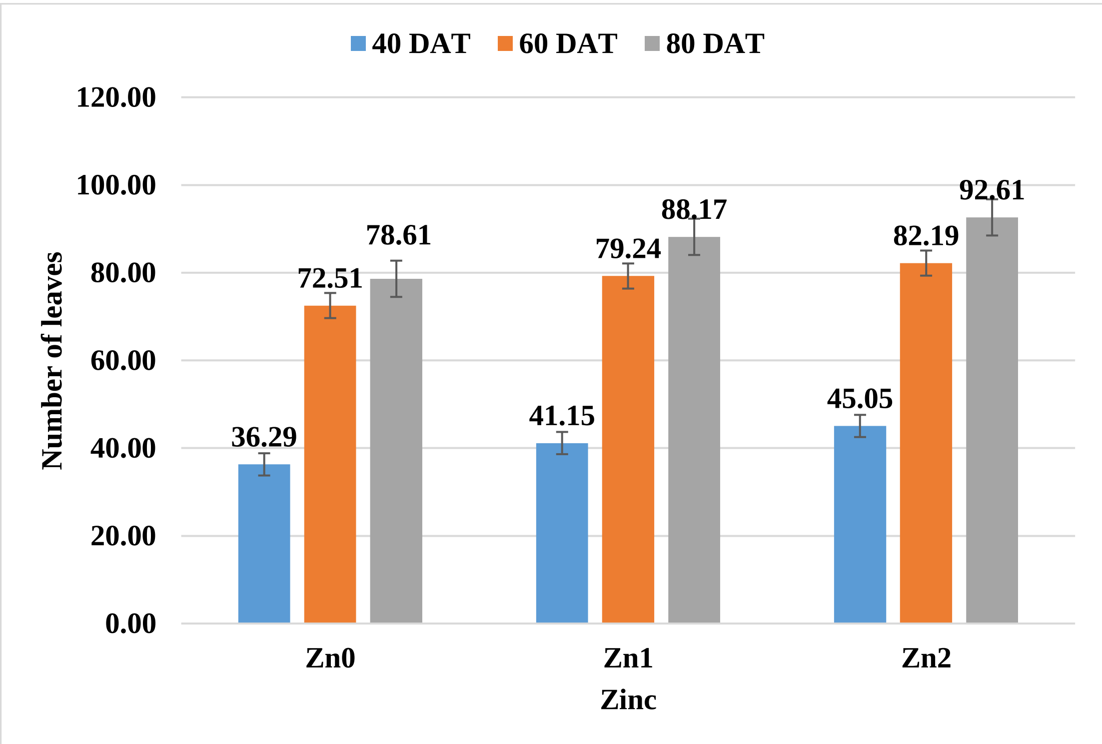

Figure 4.4: Effect of zinc on the number of leaves plant^{-1} at different DAT

Here, Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

Table 4.1.2 Combined effects of S and Zn on number of leaves of chili plant at different DAT

Treatment	Number of leaves plant^{-1}		
	40DAT	60DAT	80DAT
S_0Zn_0	**32.24 h**	**64.52 h**	**68.57 hi**
S_0Zn_1	35.63 gh	70.27 g	72.46 h
S_0Zn_2	39.72 e	78.26 def	88.55 e
S_1Zn_0	42.74 d	80.32 cd	93.54 d
SZn_1	43.55 cd	83.68 bc	94.86 cd
S_1Zn_2	**53.37 a**	**92.34 a**	**101.32 a**
S_2Zn_0	36.90 g	75.47 ef	78.70 fg
S_2Zn_1	38.22 f	77.52 de	81.63 f
S_2Zn_2	45.07 b	87.12 ab	98.51 ab
Level of significance	*	*	*
SE (±)	1.37	1.27	1.40
CV (%)	2.85	6.16	2.69

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability. Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

SE (±) = Standard Error ; CV (%) = Co–efficient of variation

In the present study it was observed that number of leaves plant^{-1} varied with different levels of sulphur and zinc application. Due to metabolic control and enzymatic processes including photosynthesis, formation and enhance the level of antioxidant enzymes and chlorophyll within plant tissues and respiration process, the growth and growth-related characteristics of the chili plants have increased as a result of sulphur and zinc.

4.1.3 Number of branches per plant

The application of different levels of sulphur (S) and zinc (Zn) fertilizer had significant effects on number of branches plant^{-1} of chili (BARI Morich 4) (Appendix VII).

Effect of S on number of branches per plant

Sulphur application to green chili variety (BARI Morich 4) showed significant variation on number of branches plant^{-1} at 40, 60, 80 days after transplanting (DAT) (Figure 4.5). Results revealed that maximum number of branches plant^{-1} (7.52, 14.42, 15.50 at 40, 60, 80 DAT respectively) was recorded from S_1 (20 kg S ha^{-1}). The minimum branches (5.97, 10.94, 11.33 at 40, 60, 80 DAT respectively) was found from control treatment, S_0 (0 kg S ha^{-1}). These findings are in line with the result obtained through the study of Vishwakarma *et al.* (1998). The increased number of branches by sulphur application is attributed to the stimulatory effect of sulphur in cell division. Sulphur influences the synthesis and metabolism of plant hormones, such as auxins and cytokinin's, which play important roles in regulating branching patterns. The importance of sulphur in cell division, cell elongation and setting of cell structure has been reported by Hadvani *et al.* (1993).

Effect of Zn on number of branches per plant

Number of branches plant^{-1} of green chili showed insignificant result due to the effect of Zn application as micronutrient at 40, 60, 80 DAT (Figure 4.6). It was found that the highest number of branches plant^{-1} (7.16 , 13.71 and 14.76) observed from Zn_2 (4 kg Zn ha^{-1}) at 40, 60 and 80 DAT respectively. On the other hand the minimum number of branches plant^{-1}(6.40, 11.69, 12.36 at 40, 60, 80 DAT respectively) was found from control treatment, Zn_0 (0 kg Zn ha^{-1}). The present finding was supported by the findings of Singh *et al.* (1989), Barche *et al.* (2011). Zinc affects the biosynthesis and transport of auxins, which are critical for the development of lateral buds and subsequent branching (Datir *et al.*, 2012).

Combined effect of S and Zn application on number of branches per plant

Significant variation was observed due to the interaction effect of S and Zn in terms of number of branches plant^{-1} of green chili at 40, 60 and 80 DAT (Table 4.1.3). Results signified that the highest number of branches plant^{-1} (8.82, 15.52 and 16.74 at 40, 60, 80 DAT respectively) was observed from S_1Zn_2 while the lowest number of branches plant^{-1} (5.70, 10.36 and 10.48 at 40, 60, 80 DAT respectively) was recorded from S_0Zn_0 followed by S_0Zn_1.

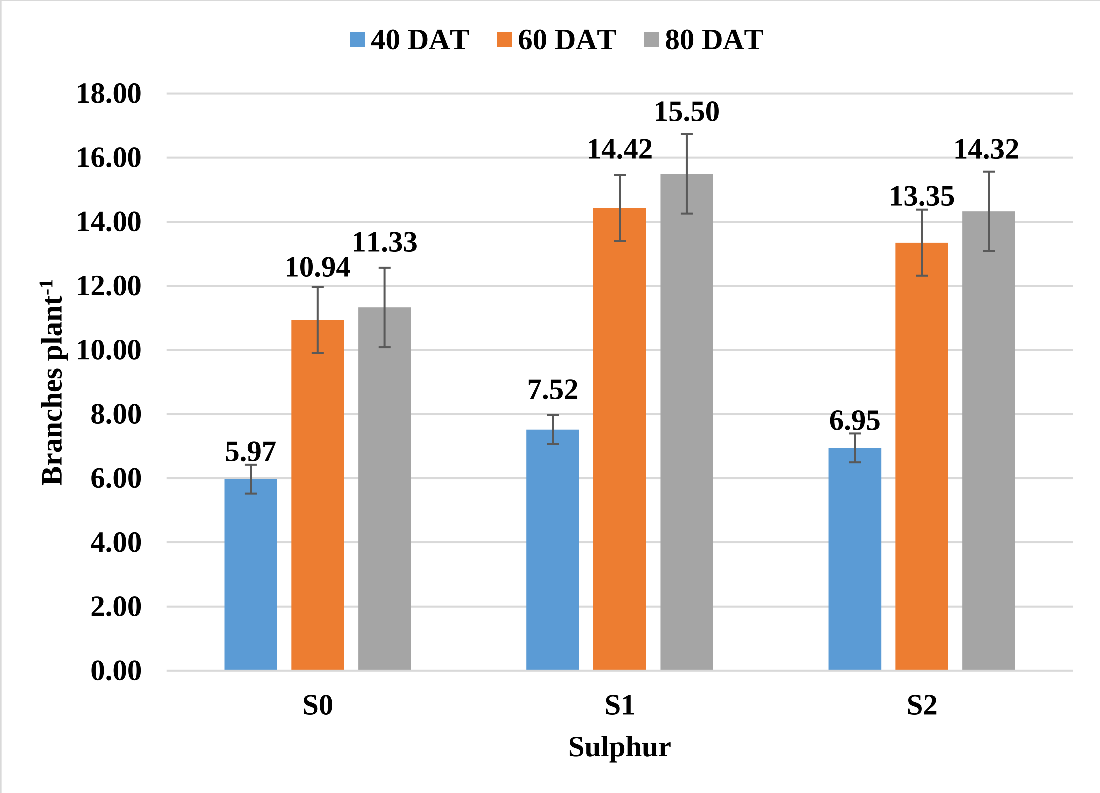

Figure 4.5: Effect of sulphur on the number of branches plant^{-1} at different DAT.

Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} , S_2 = 30 kg ha^{-1}

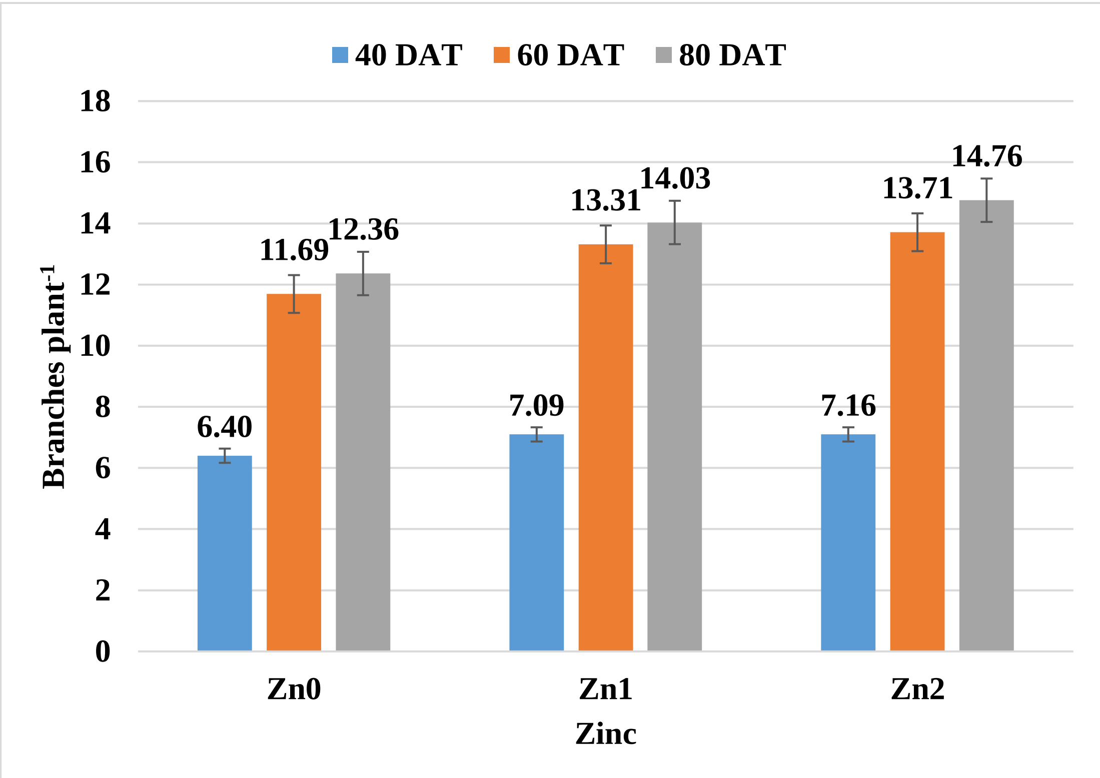

Figure 4.6: Effect of zinc on the number of branches plant^{-1} at different DAT

Here, Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

Table 4.1.3 Combined effects of S and Zn on number of branches plant^{-1} of chili

Treatment	Number of branches plant^{-1}		
	40DAT	**60DAT**	**80DAT**
S_0Zn_0	**5.70 gh**	**10.36 g**	**10.48 gh**
S_0Zn_1	5.99 g	10.64 fg	10.72 g
S_0Zn_2	6.64 def	13.32 d	14.18 e
S_1Zn_0	6.82 de	13.78 cd	14.63 de
S_1Zn_1	7.16 c	14.43 bc	15.57 cd
S_1Zn_2	**8.82 a**	**15.52 a**	**16.74 a**
S_2Zn_0	6.28 fg	11.39 f	12.42 f
S_2Zn_1	6.57 ef	11.82 ef	12.78 f
S_2Zn_2	7.38 bc	14.88 ab	15.92 bc
Level of significance	*	**	**
SE (±)	0.43	0.30	0.30
CV (%)	8.66	4.34	4.07

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability. Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

SE (±) = Standard Error ; CV (%) = Co–efficient of variation

4.2 Effects of S and Zn on yield contributing parameters of chili

4.2.1 Number of flowers per plant

The application of different levels of sulphur (S) and zinc (Zn) fertilizer and their interaction had significant effects on the number of flowers plant^{-1} of chili (BARI Morich 4) under this present trial of experiment. (Appendix VIII).

Effect of S on number of flowers per plant

Different levels of S fertilizer application showed significant result on number of flowers plant^{-1} of green chili (Table 4.2.1). Results exposed the highest number of flowers plant^{-1} (111.18) was recorded from S_1 (20 kg S ha^{-1}). In comparison, the lowest number of flowers plant^{-1} (92.45) was observed in control treatment, S_0 (0 kg S ha^{-1}). Sulphur might be responsible for synthesis of bio-assimilates which leads to a greater number of leaves and eventually partitioning of floral growth.

Effect of Zn on number flowers per plant

Number of flowers plant^{-1} of green chili plant was significantly influenced by different levels of Zn application (Table 4.2.2). Results indicated that the highest number of flowers plant^{-1} (109.24) was recorded from Zn_1 (4 kg Zn ha^{-1}) treatment. On the other hand, the lowest number of flowers plant^{-1} (94.64) was observed in control treatment, Zn_0 (0 kg Zn ha^{-1}). Thus it is likely that the higher number of flowers plant^{-1} could be due to sufficient levels of carbohydrates available for flower formation and fruit set. Supported results was also achieved by Barche *et al.* (2011).

Table 4.2.1: Effect of different level of sulphur application on yield contributing parameters of chili plant

Treatment	Flowers plant^{-1}	Fruits plant^{-1}	Fruit length(cm)	Fruit diameter(cm)
S_0	**92.45 c**	**76.29 c**	**6.04 b**	**0.41 b**
S_1	**111.18 a**	**104.57 a**	**7.10 a**	**0.56 a**
S_2	102.67 b	96.48 b	6.62 a	0.53 a
Level of significance	**	**	*	*
SE(±)	0.66	0.79	0.15	0.01
CV %	8.14	12.29	9.31	13.58

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability. Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1}

SE (±) = Standard Error ; CV (%) = Co–efficient of variation

Combined effect of S and Zn application on number of flowers per plant

The number of flowers plant^{-1} of chili was significantly affected by interaction of S and Zn application (Figure 4.7). Results revealed that the highest number of flowers plant^{-1} (121.26) was recorded from the treatment combination of S_1Zn_2 . On the other hand, the lowest number of flowers plant^{-1} (88.07) was observed in control treatment combination (S_0Zn_0). Flower production is hormonally controlled with e.g., auxin, ethylene and cytokines, enhancing floral display size and flower size (Krizek and Anderson, 2013), which is ultimately stimulated by proper amount of sulphur application. The results indicate that adequate supply of sulphur and zinc can promote the growth and development of reproductive organs and improved metabolic activities resulting in healthier and maximum number of flowering. Involvement of sulphur and zinc in photosynthesis with enhanced carbohydrate assimilation results in luxurious vegetative and floral growth (Hembrom and Singh, 2015).

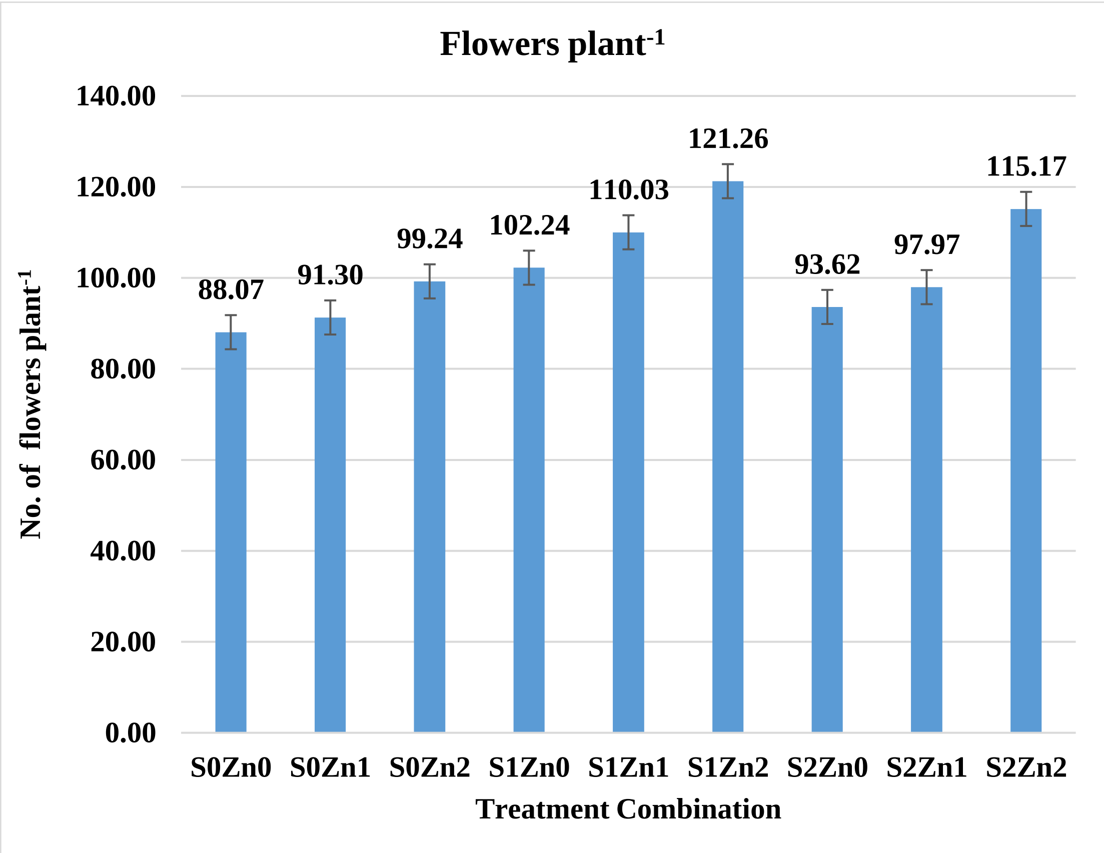

Figure 4.7: Combined effect of S and Zn on number of flowers plant^{-1} of chili

Here, S_0 = 0 kg ha^{-1}, S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

4.2.2 Number of fruits per plant

The application of different levels of sulphur (S) and zinc (Zn) fertilizer had significant effects on number of fruits plant^{-1} of chili (BARI Morich 4) during the present experiment (Appendix VIII).

Effect of S on number of fruits per plant

Significant effect was observed due to different doses of sulphur on the number of fruits plant^{-1} (Table 4.2.1). The maximum number of fruits plant^{-1} (104.57) was noticed where plants were fertilized with S_1 (20 kg S ha^{-1}) . The lowest number of fruits plant^{-1} (76.29) was obtained from S_0 (0 kg P ha^{-1}) treatment. The results indicated that the number of fruits plant^{-1} was increased with increasing of S levels to a certain levels and then decreased with increasing levels of sulphur. Saeed and Ahmad (2009) also found similar result which supported the present study.

Effect of Zn on number of fruits per plant

Effect of different doses of zinc fertilizers on number of fruits plant^{-1} was significant (Table 4.2.2). The maximum number of fruits plant^{-1} (98.81) was found at Zn_2 (4 kg Zn ha^{-1}) level whereas the minimum number of fruits plant^{-1} (80.26) was found from the control treatment Zn_0 (0 kg Zn ha^{-1}). Zinc might be responsible for synthesis of bio-assimilates which leads to a greater number of flowers and eventually formation of higher number of fruits**.** The increase in fruit yield with application of zinc sulphate may be ascribed to increase in the fruit retention on the tree consequently reducing the pre-harvest fruit drop. This result is also similar to Ali *et al.* (2008) who reported that the effect of zinc which is essential for the carbonic enzyme and photosynthesis, resulting in increase in translocation of photosynthesis in fruits; and has positive effect on retaining flowers and fruits of the plant.

Combined effect of S and Zn on number of fruits per plant

Effect of different doses of Sulphur and Zinc nutrients on the number of fruits plant^{-1} was significantly influenced (Figure 4.8). The maximum number of fruits plant^{-1} (114.09) was recorded from the treatment combination of S_1Zn_2 which was significantly different from other treatment combinations. The minimum number of fruits plant^{-1} (66.26) was counted from the treatment combination of S_0Zn_0 . *Capsicum annuum* species require adequate amount of nutrients since nutrient uptake and dry matter production (fruit yield) of pepper are closely related (Hedge, 1997).

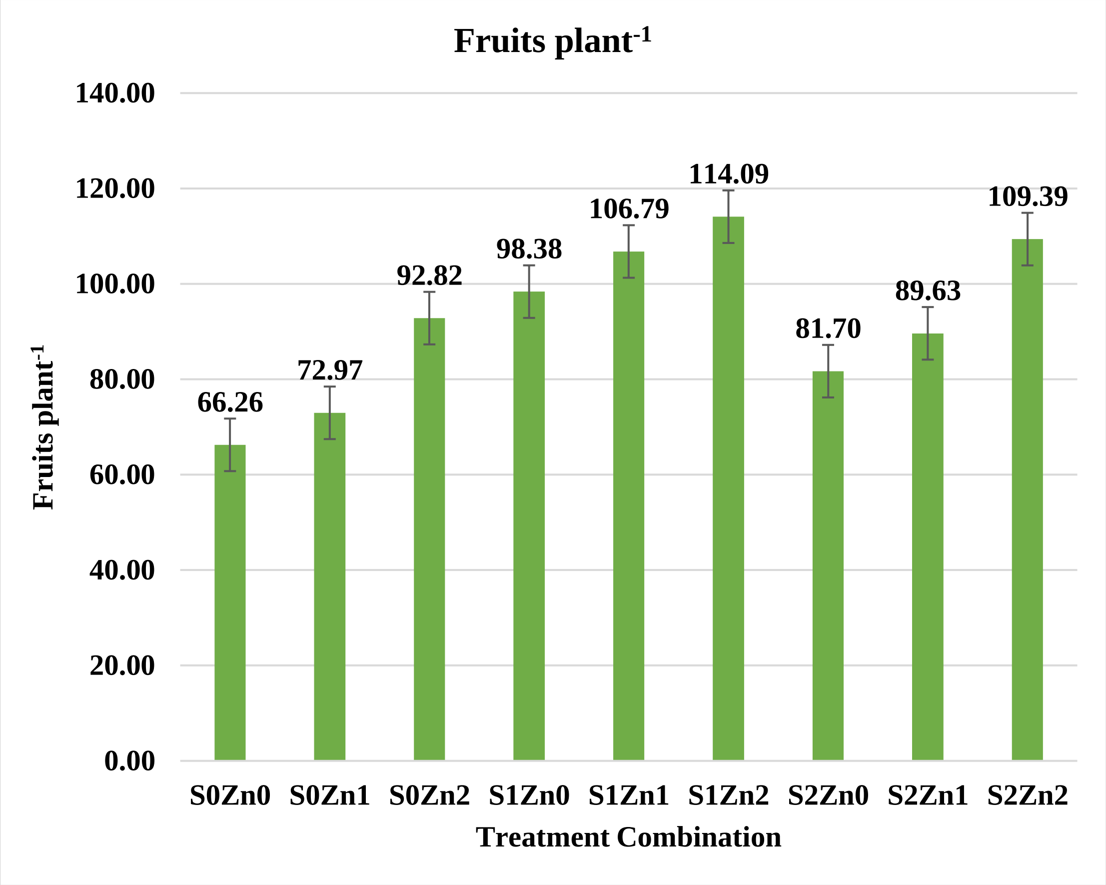

Figure 4.8: Combined effects of S and Zn on number of fruits plant^{-1} of chili
Here, S_0 = 0 kg ha^{-1}, S_1 = 20 kg ha^{-1}, S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg ha^{-1}, Zn_1 = 2 kg ha^{-1}, Zn_2 = 4 kg ha^{-1}

4.2.3 Fruit length (cm)

The application of different levels of sulphur (S) and zinc (Zn) fertilizer had significant effects on fruit length plant^{-1} of chili (BARI Morich 4) (Appendix IX).

Effect of S on the fruit length (cm) of chili

Application of S fertilizers at different doses showed significant variation on the fruit length of chili (Table 4.2.1). Among the different S fertilizer doses, S_1 showed the highest fruit length (7.10 cm) which was statistically similar (6.62 cm) with S_1 treatment. The lowest fruit length (6.04 cm) was recorded in the S_0 (control) treatment. The important role of sulphur in photosynthesis and protein synthesis which reflected on the fruit parameters and the dry matter percentage was confirmed by Arora and Lunchra, 1970.

Effect of Zn on the fruit length (cm) of chili

The fruit length as affected by different doses of Zn showed significant variation(Table 4.2.2) . Among the different doses of Zn the highest fruit length (6.93 cm) was observed in Zn_2(4 kg Zn ha^{-1}) which was statistically similar to Zn_1 (2 kg Zn ha^{-1}) treatment (6.45 cm). The lowest length of fruit (6.01) was observed S_0 treatment. Length of fruit significantly increased by zinc application by improving cell size or cell number (Khayyat *et al.,* 2007). The increase in fruit length and fruit diameter might be due to more accumulation of photosynthesis which were synthesized in the leaf and translocated towards the fruit. The increased and accumulation of photosynthesis was probably due to more vigor and growth (Trehan and Grewal, 1981).

Combined effect of S and Zn on the fruit length (cm) of chili

Combined effect of different doses of S and Zn fertilizers on fruit length showed statistically significant variation (Figure 4.9). The highest fruit length (7.79 cm) was recorded in the treatment combination of S_1Zn_2 while the lowest fruit length (5.90 cm) was found in S_0Zn_0 treatment (control) which was statistically similar to S_0Zn_1 treatment combination (5.92 cm).

Table 4.2.2: Effect of different level of zinc (Zn) application on flowers plant^{-1} , fruits plant^{-1} , fruit length (cm) and fruit diameter (cm) of chili plant

Treatment	Flowers plant^{-1}	Fruits plant^{-1}	Fruit length(cm)	Fruit diameter(cm)
Zn_0	**94.64 c**	**80.26 b**	**6.01 b**	**0.43 b**
Zn_1	102.41 b	98.26 ab	6.45 a	0.52 a
Zn_2	**109.24 a**	**98.81 a**	**6.93 a**	**0.58 a**
Level of significance	**	**	*	**
SE(±)	0.66	0.79	0.15	0.01
CV %	8.14	12.29	9.31	13.58

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability. Here, Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}
SE (±) = Standard Error ; CV (%) = Co–efficient of variation

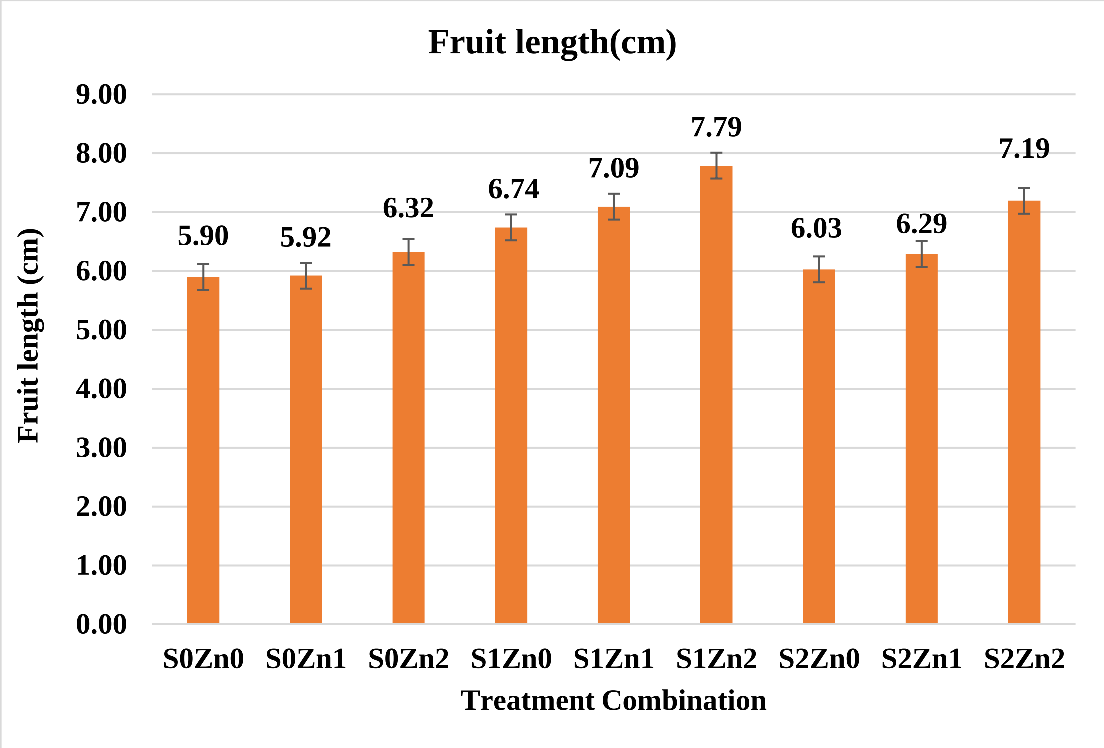

Figure 4.9: Combined effects of S and Zn on fruit length of chili plant
Here, S_0 = 0 kg ha^{-1}, S_1 = 20 kg ha^{-1}, S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

4.2.4 Fruit diameter (cm)

The application of different levels of sulphur (S) and zinc (Zn) fertilizer had significant effects on fruit diameter plant^{-1} of chili (BARI Morich 4) (Appendix IX).

Effect of S on the fruit diameter (cm)

Different levels of S application showed significant effect on fruit diameter of green chili plant^{-1} (Table 4.2.1). Results exposed the highest fruit diameter (0.56 cm) was recorded from S_1 (20 kg S ha^{-1}) which was statistically equal with S_2 (30 kg S ha^{-1}) that was 0.53 cm. In comparison, the lowest fruit diameter (0.41 cm) was observed in control treatment, S_0 (0 kg S ha^{-1}).

Effect of Zn on the fruit diameter (cm)

Fruit diameter of green chili was significantly influenced by different levels of Zn application (Table 4.2.2). Results signified that the highest fruit diameter (0.58 cm) was recorded from Zn_2 (4 kg Zn ha^{-1}) followed by Zn_1 (2 kg Zn ha^{-1}) which was 0.52 cm whereas the lowest fruit diameter (0.43 cm) was observed in control treatment, Zn_0 (0 kg Zn ha^{-1}).

Combined effect of S and Zn on the fruit diameter (cm)

The fruit diameter of green chili was significantly affected by interaction of S and Zn under this present trial (Figure 4.10). Results indicated that the highest fruit diameter (0.63 cm) was recorded from the treatment combination of S_1Zn_2 followed by S_2Zn_2 (0.60 cm). Alternatively, the lowest fruit diameter (0.36 cm) was observed in control treatment combination (S_0Zn_0) followed by S_0Zn_1 (0.41 cm)

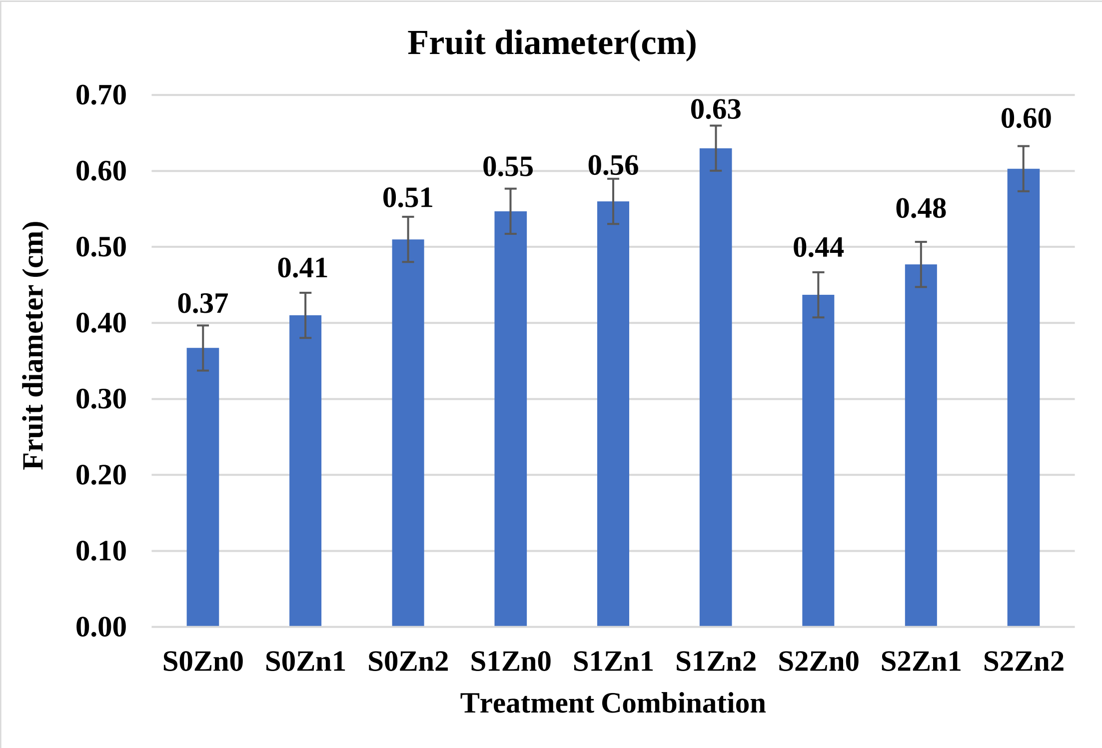

Figure 4.10: Combined effects of S and Zn on Fruit diameter of chili plant

Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

4.3 Yield parameters

4.3.1 Individual fruit weight

The application of different levels of sulphur (S) and zinc (Zn) fertilizer had significant effects on individual fruit weight of chili (BARI Morich 4) (Appendix IX).

Effect of S on Individual fruit weight

Different doses of S fertilizers showed significant variations in respect of weight of fruit of chili (Table 4.3.1). Among the different doses of S fertilizers, S_1 showed the highest individual fruit weight (1.73 g) which is closely associated with S_1 treatment (1.64 g).

The lowest weight of fruits (1.51 g) was observed S_0 (control) treatment. It could be stated that application of sulphur had a stimulative effect on the growth and yield characteristics of chili plant. The favorable effects of sulphur may be due to the fact that it is essential element for metabolism especially protein synthesis (Freney *et al.,* 1978).

Effect of Zn on individual fruit weight

Different doses of Zn fertilizers showed significant variations in respect of weight of fruit of chili (Table 4.3.2). Among the different doses of Zn fertilizers, Zn_2 showed the highest individual fruit weight (1.69 g) which was statistically similar to Zn_1 treatment (1.65 g). The lowest weight of fruits (1.48 g) was observed Zn_0 (control) treatment. Similar finding was also observed by Barche *et al.* (2011). Application of zinc improves weight of chili, because zinc expanded the cells and cell division, and work in the volume of intercellular space in mesocarpic cells in addition to quick translocation of metabolites and to sink fruits (Brahmachari and Rani, 2001) and effect of zinc, which is necessary for the carbonic enzymes that is present in all photosynthetic tissues, and needed for chlorophyll biosynthesis, thus increased the translocation of photosynthetic assimilates (Sindhu *et al.,* 1998) found the results that weight of fruit maximize by the treatments of zinc.

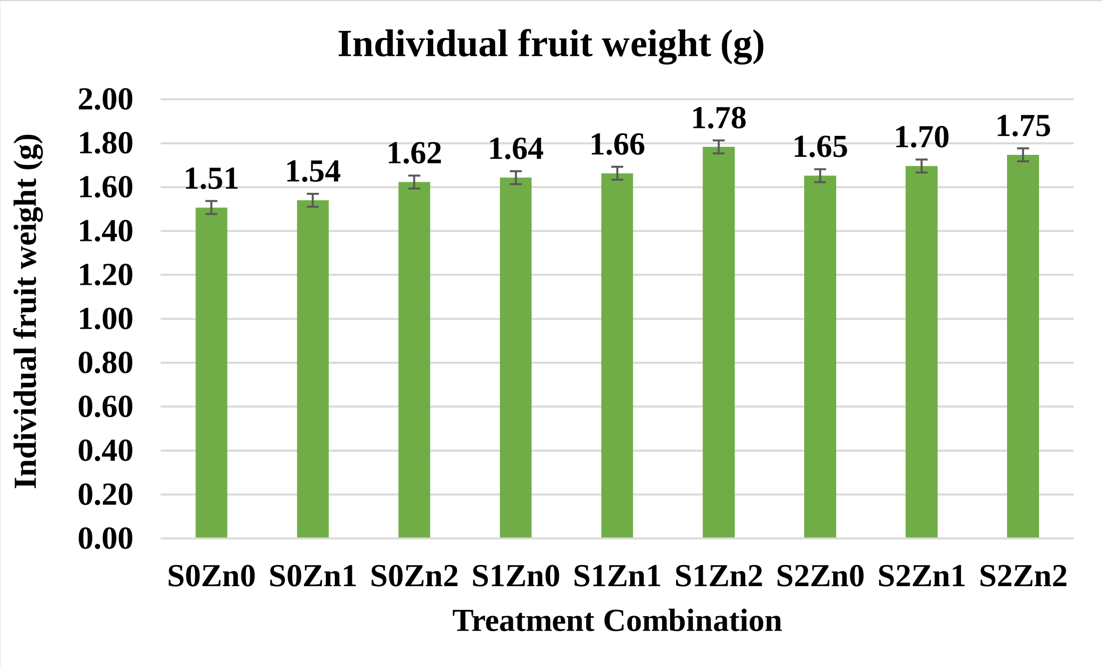

Figure 4.11: Combined effects of S and Zn on individual fruit weight of chili

Here, $S_0 = 0$ kg ha^{-1} , $S_1 = 20$ kg ha^{-1} ,$S_2 = 30$ kg ha^{-1} and $Zn_0 = 0$ kg ha^{-1} , $Zn_1 = 2$ kg ha^{-1} , $Zn_2 = 4$ kg ha^{-1}

Interaction effect of S and Zn on the individual fruit weight

The combined effect of different doses of S and Zn fertilizers on weight of fruit was significant (Figure 4.11). The highest fruit weight (1.78 g) was recorded with the treatment combination of S_1Zn_2 which was statistically similar to S_2Zn_1 (1.70) treatment combination. On the other hand, the lowest fruit weight (1.51 g) was found in S_0Zn_0 (control) treatment. It might be occurred due to S and Zn role in maintaining cellular membranes involving structural orientations of macromolecules and develop healthy fruits. Zhang *et al.* (2010) found that the application of sulphur and zinc increased the fruit weight of chili by 19% compared to the control treatment. The study also found that the application of sulphur and zinc increased the number of fruits per plant by 12%. Liu *et al.* (2011) found that the application of sulphur and zinc increased the fruit weight of chili by 22% compared to the control treatment. The study also found that the application of sulphur and zinc increased the length and width of the fruits.

Table 4.3.1: Effect of different level of sulphur application on individual fruit weight (g) , average fruit weight plant^{-1} , fruit yield (t ha^{-1}) of chili plant

Treatment	Individual fruit weight (g)	Average fruit weight plant^{-1} (g)	Fruit yield (t ha^{-1})
S_0	**1.51 b**	**119.99 c**	**18.54 c**
S_1	**1.73 a**	**177.27 a**	**28.21 a**
S_2	1.64 a	159.75 b	25.41 b
Level of significance	*	**	**
SE(±)	0.02	2.90	0.15
CV %	5.72	7.39	5.04

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability. Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1}

SE (±) = Standard Error; CV (%) = Co–efficient of variation

4.3.1 Average fruit weight per plant

The application of different levels of sulphur (S) and zinc (Zn) fertilizer had significant effects on average fruit weight plant^{-1} of chili (BARI Morich 4) under this present field experiment (Appendix X).

Effect of S on average fruit weight per plant

Significant variation was found for different levels of S application to green chili plants on average fruit weight plant^{-1} (Table 4.3.1). Result revealed that the highest average fruit weight plant^{-1} (177.27 g) was found from S_1 (20 kg S ha^{-1}) where the lowest average fruit weight plant^{-1} (119.99 g) was obtained by control treatment,S_0 (0 kg ha^{-1}).

Effect of Zn on average fruit weight per plant

Average fruit weight of green chili differed significantly due to the effect of Zn application as micronutrient (Table 4.3.2). It was found that the highest average fruit weight (169.05 g) was found from Zn_1 (4 kg Zn ha^{-1}) while the lowest average fruit weight (126.99 g) was found from control treatment, Zn_0 (0 kg Zn ha^{-1}). Similar result was also found by Mahesh and Sen (2005) which was conformity with the present findings.

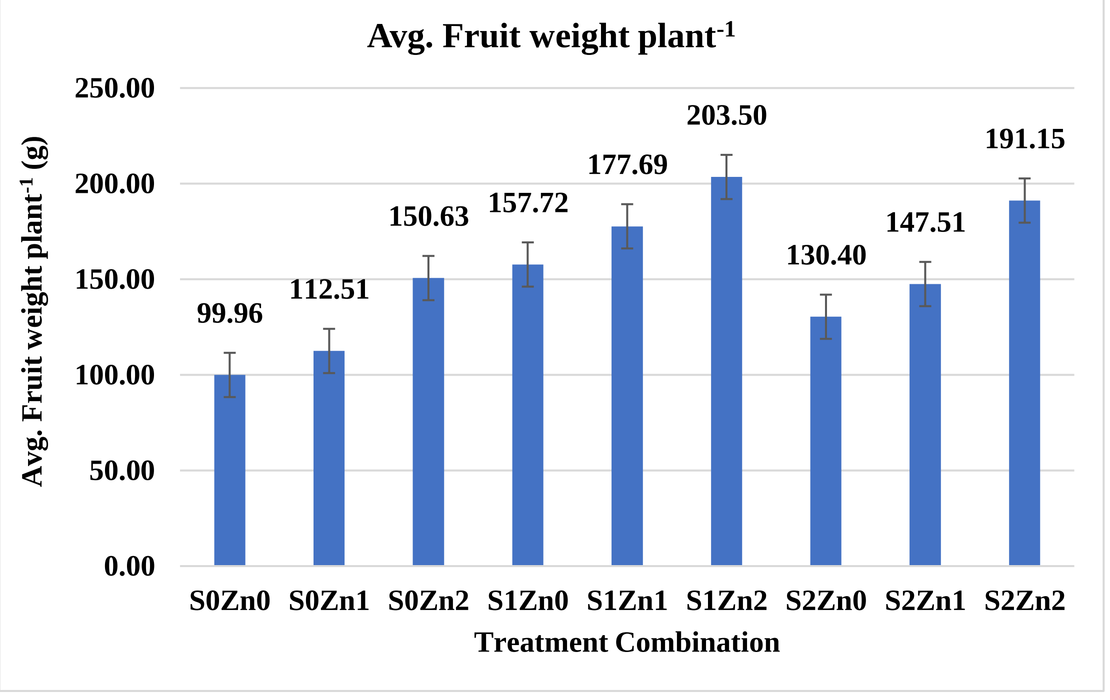

Figure 4.12: Combined effects of S and Zn on average fruit weight plant^{-1} of chili

Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

Interactive Effect of S and Zn on average fruit weight per plant

Combined effect of S and Zn application to green chili plants showed significant variation on average fruit weight plant^{-1} (Figure 4.12). Results demonstrated that the highest average fruit weight (203.50 g) was recorded from S_1Zn_2 which was statistically similar with S_2Zn_2 (191.15 g) whereas the lowest average fruit weight (99.96 g) was observed from S_0Zn_0 treatment combination.

Table 4.3.2: Effect of different level of zinc (Zn) application on individual fruit weight (g) , average fruit weight plant^{-1} and fruit yield (t ha^{-1}) of chili plant

Treatment	Individual fruit weight (g)	Average fruit weight plant^{-1} (g)	Fruit yield (t ha^{-1})
Zn_0	**1.48 b**	**126.99 c**	**19.88 c**
Zn_1	1.65 a	160.97 b	24.94 b
Zn_2	**1.69 a**	**169.05 a**	**27.35 a**
Level of significance	*	**	**
SE(±)	0.02	2.90	1.59
CV %	5.72	7.39	5.04

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability. Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1}

SE (±) = Standard Error; CV (%) = Co–efficient of variation

4.3.2 Fruit yield ha^{-1}

The application of different levels of sulphur (S) and zinc (Zn) fertilizer had significant effects on fruit yield ha^{-1} of chili (BARI Morich 4) (Appendix X).

Effect of S on average fruit yield ha^{-1}

Different levels of S application to green chili plants had significant effect on fruit yield ha^{-1} (Table 4.3.1). Result revealed that the highest fruit yield ha^{-1} (28.21 t) was found from S_1 (20 kg S ha^{-1}) where the lowest fruit yield ha^{-1} (18.54 t) was obtained by control treatment, S_0 (0 kg S ha^{-1}). This might explained the importance of S in improving yield and quality by influencing the S containing amino acids, which are the building blocks of proteins, and along with starch are responsible for formation of fruits (Arora and Luchra, 1970 and Gopal *et al.*, 2003,)

Effect of Zn on average fruit yield ha^{-1}

Significant variation was found for fruit yield ha^{-1} of green chili influenced by different levels of Zn application(Table 4.3.2). It was found that the highest fruit yield ha^{-1} (27.35 t) was found from Zn_2 (4 kg Zn ha^{-1}) where the lowest fruit yield ha^{-1} (19.88 t) was found from control treatment, Zn_0 (0 kg Zn ha^{-1}). Similar results were also observed by Patil *et al.* (2011), Rohidas *et al.* (2010) and Sindhu and Tiwari (1989).

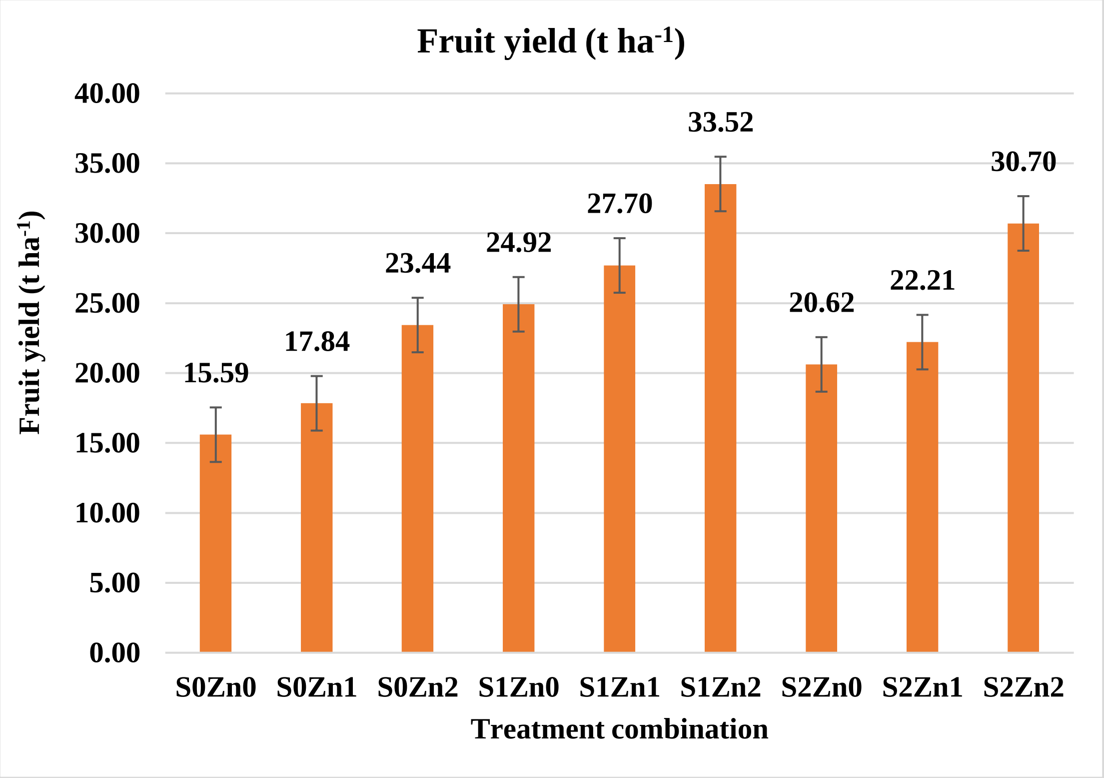

Figure 4.13: Combined effects of S and Zn on the yield (ton) ha^{-1} of chili

Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1} and Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}

Interactive Effect of S and Zn on average fruit yield ha^{-1}

Fruit yield ha^{-1} of green chili was significantly affected by the combination of S and Zn application (Figure 4.13, Table 4.3.3). Results verified that the highest fruit yield ha^{-1} (33.52 t) was recorded from S_1Zn_2 which was statistically similar with S_2Zn_2 (30.70 t) whereas the lowest fruit yield ha^{-1} (15.59 t) was observed from S_0Zn_0 treatment which was statistically similar with S_0Zn_1 (17.83 t).

Table 4.3.3 Combined Effect of S and Zn on average fruit weight plant^{-1} and fruit yield ton ha^{-1}

Treatment	Average fruit weight plant^{-1} (g)	Fruit yield (t ha^{-1})
S_0Zn_0	**99.96 i**	**15.59 h**
S_0Zn_1	112.51 h	17.83 gh
S_0Zn_2	150.62 ef	23.43 de
S_1Zn_0	157.72 de	24.91 cde
S_1Zn_1	177.69 cd	27.69 bc
S_1Zn_2	**203.49 a**	**33.52 a**
S_2Zn_0	130.39 g	20.62 ef
S_2Zn_1	147.50 efg	22.21 e
S_2Zn_2	191.15 ab	30.70 ab
Level of significance	**	**
SE	5.03	0.27
CV (%)	7.39	5.04

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability. Here, S_0 = 0 kg ha^{-1} , S_1 = 20 kg ha^{-1} ,S_2 = 30 kg ha^{-1} , Zn_0 = 0 kg ha^{-1} , Zn_1 = 2 kg ha^{-1} , Zn_2 = 4 kg ha^{-1}
SE (±) = Standard Error; CV (%) = Co–efficient of variation

Chapter V

Summary and Conclusion

Chapter IV

SUMMARY AND CONCLUSION

The experiment was conducted at Agronomy Farm of Sher-e-Bangla Agricultural University, Sher-e- Bangla Nagar, Dhaka, Bangladesh during the period From November, 2021 to April, 2022 to study the effect of S and Zn on growth and yield of chili. The variety "BARI Morich 4" was used as experimental materials. The experiment consisted of two factors: Factor A: Sulphur application (3 levels) as; (i) S_0: 0 kg S ha^{-1} (ii) S_1: 20 kg S ha^{-1} (iii) S_2: 30 kg S ha^{-1} and Factor B:Zinc application (3 levels) as; (i) Zn_0: 0 kg Zn ha^{-1} (ii) Zn_1: 2 kg Zn ha^{-1} (iii) Zn_2: 4 kg Zn ha^{-1}. The two factors experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Data on growth, yield contributing characters and yields were recorded and statistically significant variation was observed for different treatment.

The individual treatment of S application showed significant variations on the growth and yield contributing parameters of chili. Results showed that in terms of S effect, the highest plant height 66.12 cm, number of leaves $plant^{-1}$ 96.13 and number of branches $plant^{-1}$ 15.50 at 80 DAT were recorded from S_1(20 kg S ha^{-1}). Apart from the highest number of fruits $plant^{-1}$ (104.57), flowers $plant^{-1}$ (111.18) , fruit length (7.10 cm) , fruit diameter (0.56 cm), individual fruit weight (1.73 g) , average fruit weight $plant^{-1}$ (177.27 g), fruit yield ha^{-1} (28.21 t) were also observed from S_1 treatment.

Different levels of Zn application also had significant variation on growth and yield contributing parameter of green chili. Results showed that in terms of Zn effect, the highest plant height 66.06 cm, number of leaves $plant^{-1}$ 92.61 cm, highest number of branches $plant^{-1}$ 14.76 at 80 DAT were recorded from Zn_2 (4 kg Zn ha^{-1}). Again the highest number of flowers $plant^{-1}$ (109.24), fruits $plant^{-1}$ (98.81), fruit length (6.93 cm), fruit diameter (0.54 cm) , individual fruit weight (1.69 g) , average fruit weight $plant^{-1}$ (169.05 g), fruit yield ha^{-1} (27.35 t) were observed from Zn_2 treatment.

Considering combined effect of S and Zn, growth contributing parameters such as the tallest plant 74.83 cm, number of leaves $plant^{-1}$ 101.32, maximum number of branches $plant^{-1}$ 16.74 at 80 DAT were recorded from S_1Zn_2 treatment combination. Again the yield contributing parameters such as number of highest number of flowers $plant^{-1}$

(121.26), maximum number of fruits plant^{-1} (114.09), highest fruit length (7.79 cm), highest fruit diameter (0.63 cm) ,highest individual fruit weight (1.78 g), average fruit weight plant^{-1} (203.50 g) and fruit yield ha^{-1} (33.52 t)were also recorded from S_1Zn_2.

Conclusion and Recommendation:

From the present study, the following conclusion and recommendation maybe drawn:

- Individual effect of S and Zn on growth and yield of chili plant were found significant under this present trial.
- In case of sulphur (S) application, S_1 treatment (20 kg S ha^{-1}) was found suitable dose which gave the highest yield (28.21 t ha^{-1}).
- In case of zinc (Zn) application, Zn_2 treatment (4 kg Zn ha^{-1}) was suitable dose which gave the highest yield (27.35 t ha^{-1}).
- Finally, for the interactive effect of sulphur (S) and zinc (Zn) , S_1Zn_2 treatment combination (20 kg S ha^{-1} with 4 kg Zn ha^{-1}) was found most suitable dose which gave the highest yield (33.52 t ha^{-1})
- Further research works at different AEZ of the country are needed to identify suitable doses of S and Zn for chili.

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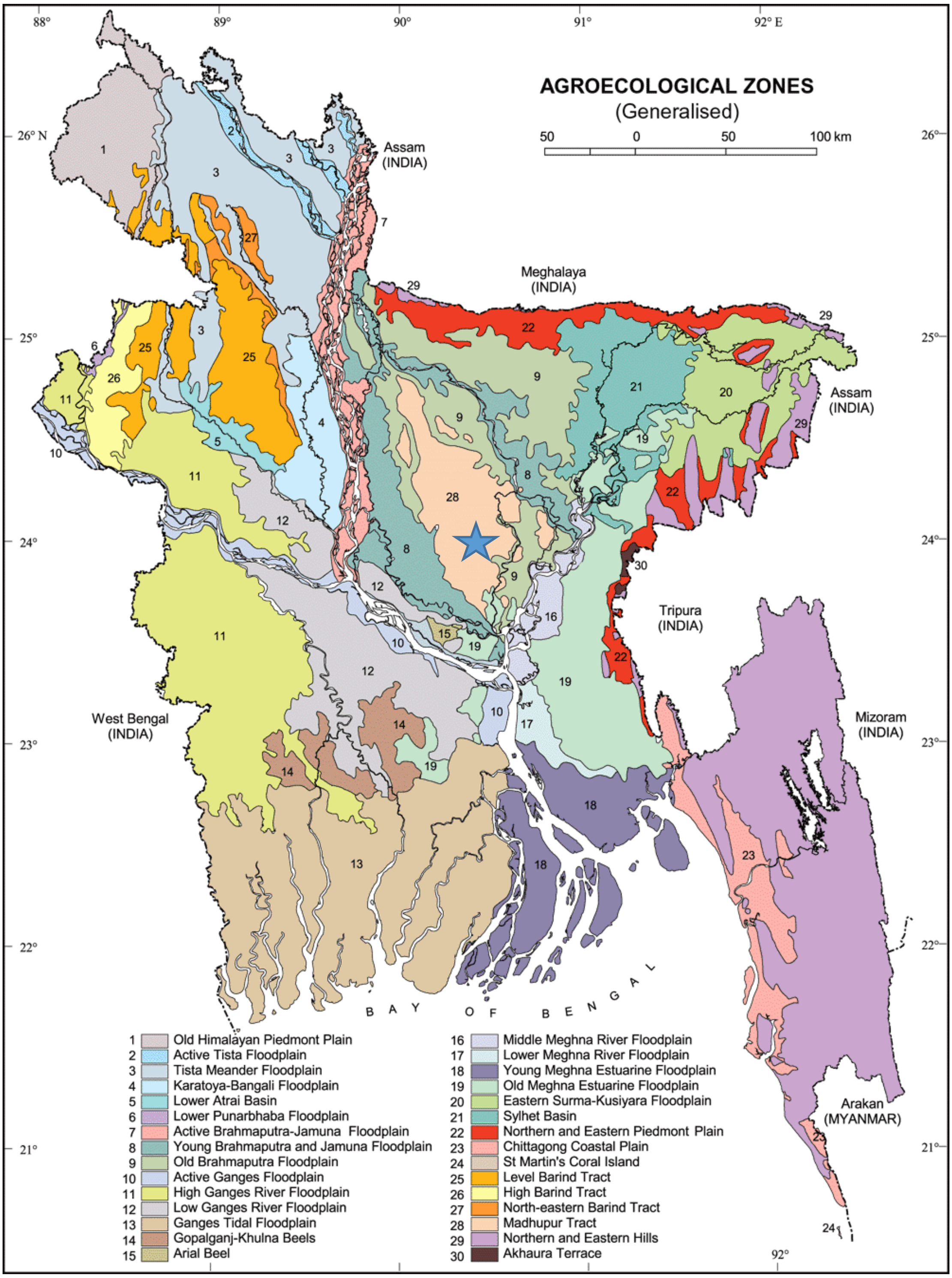
Appendices

APPENDICES

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



Appendix II. **Monthly records of air temperature, relative humidity and rainfall during the period from November 2021 to April 2022**

Year	Month	Air temperature (°C)			Relative Humidity (%)	Rainfall(mm)
		Max	Min	Mean		
2021	November	29.6	19.2	24.4	73	34.4
2021	December	26.4	14.1	20.2	73	12.8
2022	January	25.4	12.7	19.0	71	7.7
2022	February	28.1	15.5	21.8	64	28.9
2022	March	32.5	20.4	26.4	62	65.8
2022	April	33.7	23.6	28.6	71	156.3

Source: Bangladesh Meteorological Department, Agargaon, Dhaka – 1207

Appendix III. Morphological characteristics of experimental field

Morphological features	Characteristics
Location	Agronomy farm, SAU, Dhaka
AEZ No. and name	AEZ-28, Madhupur Tract
General soil type	Shallow Red Brown Terrace Soil
Soil series	Tejgaon
Topography	Fairly leveled
Depth of inundation	Above flood level
Drainage condition	Well drained
Land type	High land

Appendix IV. Physical and chemical properties of the initial soil of the experimental field

Physical properties	Values
%Sand (2-0.02 mm)	30%
%Silt (0.02-0.002 mm)	40%
%Clay (<0.002 mm)	30%
Textural class	Clay loam
Particle density	2.57 g cc^{-1}

Chemical properties	Values
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.06
Available P(ppm)	20.0
Available S(ppm)	14.7

Appendix V. Significant effect on plant height of chili affected by sulphur and zinc

Sources of Variation	Degrees of freedom	Mean square value		
		40 DAT	60DAT	80DAT
Factor A (Sulphur)	2	46.87**	113.0*	322.19**
Factor B (Zinc)	2	39.02**	87.25*	207.32**
Factor AB	4	10.43*	51.83*	23.26*
Error	18	3.25	17.09	7.50

** Significant at 1% level * Significant at 5% lev

Appendix VI. Significant effect on number of leaves plant^{-1} of chili affected by sulphur and zinc at different DAT

Sources of variation	Degrees of freedom	Mean square value		
		40 DAT	60DAT	80DAT
Factor A (Sulphur)	2	257.49**	690.05**	1124.72**
Factor B (Zinc)	2	173.35**	221.55*	460.82**
Factor AB	4	17.54*	16.81*	25.51*
Error	18	5.66	4.87	5.95

** Significant at 1% level * Significant at 5% level

Appendix VII. Significant effect on number of branches plant^{-1} of chili affected by sulphur and zinc at different DAT

Sources of variation	Degrees of freedom	Mean square value		
		40 DAT	60DAT	80DAT
Factor A (Sulphur)	2	5.47**	28.64**	41.61**
Factor B (Zinc)	2	1.20	10.30*	13.59**
Factor AB	4	1.81*	2.33*	2.76**
Error	18	0.56	0.28	0.28

** Significant at 1% level * Significant at 5% level

Appendix VIII. **Significant effect on flowers plant^{-1} , fruits plant^{-1} of chili as affected by sulphur and zinc**

Sources of variation	Degrees of freedom	Mean square of value	
		Flowers/plant	Fruits/plant
Factor A (Sulphur)	2	791.62**	1910.07**
Factor B (Zinc)	2	480.37**	1003.26**
Factor AB	4	122.60**	182.321**
Error	18	3.969	5.71

** Significant at 1% level   * Significant at 5% level

Appendix IX. **Significant effect on fruit length, fruit diameter, fruit weight of chili as affected by sulphur and zinc**

Sources of Variation	Degrees of freedom	Mean square of value		
		Fruit length	Fruit Diameter	Fruit weight
Factor A (Sulphur)	2	2.56**	0.05**	0.03*
Factor B (Zinc)	2	0.83*	0.03**	0.02*
Factor AB	4	0.91*	0.006*	0.01*
Error	18	0.21	0.00097	0.004

** Significant at 1% level   * Significant at 5% level

Appendix X. Significant effect on yield ha^{-1} (ton), average weight of fruit plant^{-1} of chili as affected by sulphur and zinc

Sources of Variation	Degrees of freedom	Mean Square value	
		Yield (ton ha^{-1})	Average weight of fruit plant^{-1}
Factor A (Sulphur)	2	159.23**	7753.36**
Factor B (Zinc)	2	76.29**	4483.11**
Factor AB	4	11.87**	1106.41**
Error	18	0.59	75.97

** Significant at 1% level * Significant at 5% level

LIST OF PLATES

Plate 1: Layout of the experimental plot

Plate 2: Experimental site of chili field

Plate 3: A transplanted seedling

Plate 4: Plant during vegetative stage

Plate 5: Plant during flowering stage

Plate 6: Collection of data on the field

Plate 7: An infected plant

Plate 8: Fruiting stage of chili

Plate 9: Harvested fruits of chili