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Response of Sulphur and Zinc on The Growth and Yield Traits of Sesame (*Sesamum indicum* L.) At Old Himalayan Piedmont Plain Soil

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Abstract

A field experiment was carried at the Agronomy Research Field, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh to find out the effect of sulphur and zinc on the growth and yield traits of sesame. The experiment consisted two factorial naming Factor A: Three levels of sulphur as 0 (S_1), 18 (S_2) and 24 (S_3) (0, 100, 150 kg gypsum/ha), and Factor B: Three levels of zinc as 0 (Zn_1), 1.44 (Zn_2) and 2.88 (Zn_3) (0, 4.0, 8.0kg zinc sulphate/ha). The total treatment combinations were i) T_1 (S_1Zn_1), ii) T2 (S_1Zn_2), iii) T_3 (S_1Zn_3), iv) T_4 (S_2Zn_1), v) T_5 (S_2Zn_2), vi) T_6 (S_2Zn_3), vii) T_7 (S_3Zn_1), viii) T_8 (S_3Zn_2), ix) T_9 (S_3Zn_3). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Seasame cv. BARITil 4 was used as test crop. The experimental results revealed that sulphur (18 kg ha^{-1}) + zinc (1.44 kg ha^{-1}) (S_2Zn_2) applications greatly increased the leaf,

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petiole, stem and root at different days after sowing. Higher dry weight of different parts and yield traits i.e. no of capsules and capsules weight were produced by the application of sulphur (18 kg ha^{-1}) + zinc (1.44 kg ha^{-1}) among all treatment combinations at different growth stage.

Keywords: Sulphur, zinc, growth, yield traits, sesame.

INTRODUCTION

Sesame (*Sesamum indicum* L. Wilczek) is one of the important oil seed crops among the other oil seed crops under the family of Pedaliaceae in Bangladesh (Islam et al., 2008). It is one of the oldest and very essential oil seed crops known, is extensively grownin tropical and subtropical areas of the Globe (Kurt et al, 2016). *Sesamum indicum*, the cultivated type originated in India and is tolerant to drought like conditions, growing where other crops fail. Sesame has one of the highest oil contents of any seed with a rich nutty flavor, it is a common ingredient in cuisines across the world, it is an ancient and well known crop in Bangladesh (Islam et al., 2008). The sesame seeds contain 50% oil, 20% protein, although limited amount of lysine but rich in tryptophan and methionine (Islam et al., 2008). Sesame oil is rich in linoleic and oleic acids, the predominance of gamma-tocopherol over the other isomers of vitamin E and high content of fat soluble ligans (sesamin and sesamolin) (Islam et al., 2008). Sesamin and sesamolin are formed during refinement the two phenolic antioxidants of sesamol and sesaminol. Both of these substances belong to lignans and have been shown to possess cholesterol-lowering effect in humans (Hirata et al., 1996), and prevent high blood pressure and increase vitamin E supplies in animals (Kamal-Eldin et al., 1995). Sesame oil is highly stable and rarely turns rancid in hot climates. It is rich in unsaturated fatty acids where the fatty acids composition is 14% saturated, 39% mono-unsaturated, and 46% poly-unsaturated fatty acids (Toma and Tabekhia, 1979). Carbohydrates in sesame seed are composed of 3.2% glucose, 2.6% fructose and 0.2% sucrose while the remaining quantity is dietary fibers. Sesame seeds have desirable physiological effects including antioxidant activity, blood pressure and serum lipid lowering potential as proven in experimental animals and humans (Sirato-Yasumoto et al., 2001). Sesame seeds are used as an excellent source of copper and calcium. It is also rich in phosphorous, iron, magnesium, manganese, zinc and vitamin B1 (Hasan et al., 2000). Internal production of oilseed crops in Bangladesh is not quite enough to meet the demand. Islam et al. (2008) reported that 68% of oil requirement is deficit over the total requirement in our country.

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The area and production of sesame is gradually decreasing regrettably (AIS, 2018), and it is indispensable to produce extra crop from decreasing agricultural land area for mitigating the appropriate food requirements (Islam et al., 2017a). To fulfill the requirement, the country has to import edible oils at the cost of huge amount of foreign exchanges. Therefore, the country has to increase its production to satisfy its internal demand with the adoption of appropriate improved technologies. Cultivation of oil seed crops including sesame is approaching to the less fertile and/or problems soils day by day with improper management practices due to growing more profitable rice based crops in normal soils to meet up the fundamental oil demand in Bangladesh (Islam et al., 2017b). Researchers also have paid very little attention to sesame in comparison with other cereals and grain crops. Consequently the production as well as productivity is greatly lower in Bangladesh as compared with leading sesame producing countries of the world. Therefore, it is utmost necessary to various practices may help to increase productivity. The yield of sesame is very low in Bangladesh as compare other sesame growing countries due to improper use fertilizers and choice of less fertile marginal lands. For increasing higher yield and quality of sesame, balanced fertilization with macro- and micro-nutrients is important (Deotale et al., 1998; Ghosh et al., 2002; Sanga, 2013). Sulphur (S) is recognized as one of the essential elements for plant growth particularly for oilseed crops. It is responsible for increasing the oil content as well as pungency in oil by forming certain disulphide linkages. Oilseed crops require more S than cereal crops, and S deficiency hampers N metabolism in plants as well as synthesis of S-containing amino acids, and thus exerts adverse effects on both seed and oil yield. The S is essential for the plant growth and development, plays a key role in plant metabolism, synthesis of essential oils, and formation chlorophyll (Ajai Singh et al., 2000). It also enhances cell development, cold resistance, and drought hardness (Patel and Shelke, 1995), and constituent of a number of organic compounds (Shamina and Imamul, 2003), oil storage organs particularly oil glands (Jaggi et al., 2000) and vitamin B1 (Thirumalaisamy et al., 2001). As like S, application of Zn significantly enhanced plant growth, yield and quality of sesame (Chaplot et al., 1992). The beneficial effects of micronutrients might be due to the activation of various enzymes and the efficient utilization of applied nutrients resulting in increased yield components (Shanker et al., 1999). Numerous physiological processes of plants enhanced by zinc (Zn) application (Khatun et al. 2018). The application of Zn alone as foliar or soil increased the yield sesame to 10-13% (Sanga, 2013). It is also reported that zinc progressed plant growth, development, and yield of sesame either through seed priming before seeding (Deotale et al., 1998). However, the growth and development of flowers, stems, leaves, the shedding of leaves, and the maturity and ripening of grains are also positively influenced and standardized by both sulphur and zinc but in absence or very less amount of sulphur and zinc, plants would be a cluster of undifferentiated cells. Sulphur and zinc are synergistically improved crop performance under normal and stress conditions in sesame (Aldesuquy and Gaber, 1993). Information regarding effect of sulphur and zinc in sesame is scarcely available in Bangladesh condition. Therefore, the present piece of research work was conducted to know the performance of sulphur and zinc on the growth and yield of sesame.

MATERIALS and METHODS

Location and duration

A field experiment was carried out at the Agronomy Research Field, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh to know the effect of sulphur and zincon the growth and yield of sesame. The geographical position of the study cite is between 25º 44.574" N and 88º 40.344" E, and is 37.35 m above sea level. The Agro Ecological Zone (AEZ) of the area is the Old Himalayan Piedmont Plain (AEZ-1) (FRG, 2012). The experiment was conducted during the period of April to June, 2018.

Soil characteristics in the experimental field

The soil of the experiment was sandy loam, which has a very poor nutrient status. The soil of the experimental sites was analyzed before sowing of the sesame. The pre-seeding total soil nitrogen (N) was 0.08%, indicating a deficiency in soil N. Soil available K, Ca, and Mg were 0.10, 2.48, and 0.29 meq $100g^{-1}$ soil, and available P, S, B, and Zn were 11.2, 7.29, 0.13, and 0.90 ppm, respectively. Based on the critical levels of these plant nutrients, N, S, Mg, B, and Zn were low; but P, K, and Ca were high. Soil pH was 5.41 and organic matter was 1.48%. The morphological, physical, and chemical properties of the soil are presented in Table 1.

Table 1. Morpho-physio-chemical properties of the soil of the research field, HSTU, Dinajpur, with the critical value and extraction method

Morphological soil properties	
Parameter	**Properties**
AEZ	AEZ-1: Old Himalayan Piedmont Plain
Land type	Highland
General soil type	Non-calcareous, brown floodplain soil
Soil series	Ranisankil
Topography	Levelled
Drainage	Good drainage system
Flood level	Above flood level
Geographic position	25.42o North Latitude, 88.39o East Longitude, 37.35m above sea level

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Physical soil properties			
Property	Value (%)	Critical value	Extraction method
Sand	56	-	-
Silt	30	-	-
Clay	14	-	-
Textural class	Sandy loam	-	Hydrometer method (Black, 1965). Determined by Marshall's triangular coordinates by USDA system
Chemical soil parameters			
Property	Value (%)	Critical value	Extraction methods
Soil pH(1:1.25, Soil:H_2O)	5.41	-	Glass-electrode pH meter with 1:1.25 soil-water ratios (Page *et al.*,1982).
Organic matter	1.42	-	Wet oxidation method (Black, 1965). Calculated by Van Bemmelen factor 1.73 (Piper, 1966).
N (%)	0.08	0.10	Micro-Kjeldahl method (Bremner and Mulvaney, 1982).
Available P (ppm)	11.20	8.0	Molybdate blue ascorbic acid (Bray and Kurtz, 1945).
Exchangeable K (meq %)	0.10	0.08	Determined by Flame photometer
Exchangeable Ca (meq %)	2.48	2.0	Atomic absorption spectrophotometer (Knudsen *et al.*, 1982)
Exchangeable Mg (meq %)	0.29	0.5	Extractable method (Hunter, 1974).
Available S (ppm)	6.29	8.0	Turbidity method using $BaCl_2$ (Fox *et al.*,1964).
Available B (ppm)	0.13	0.16	Calcium chloride extraction method(Page*et al*., 1982).
Available Zn (ppm)	0.55	0.60	Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978).

Climate

In this study, the weather data including temperature, rainfall and relative humidity (RH) during the period (April-June/2018) of experiment of HSTU campus were recorded at the HSTU Meteorological Station, HSTU, Dinajpur. The average maximum & minimum temperature, RH, and rainfall were 32.2 & 20.58°C, 79.40% and 4.18 mm, respectively. Rainfall occurred extremely at 55-61 days after sowing (DAS), i.e. grain filling stage. The climatic parameters during the experimental period are presented in Table 2.

Table 2. Monthly average temperature (minimum, maximum, and mean), relative humidity (%), and rainfall (mm) during the experiment

Months	Temperature (^{0} C)			Relative Humidity (%)	Total Rainfall (mm)
	Minimum	Maximum	Average		
April	20.4	35.2	27.8	69	7.0
May	23.5	34.3	28.9	77	209
June	25.2	32.8	29	87	225

Experimental design and treatments

The research work was comprised as two factors of three levels of S as 0 (S_1), 18(S_2), and 24(S_3) (0, 100, 150 kg gypsum/ha) and three levels of Zn as 0 (Zn_1), 1.44 (Zn_2) and 2.88(Zn_3) (0,4,

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8.0kg zinc sulphate/ha). Sesame variety BARI Til4 was used as test crop. It was replicated in thrice with Randomized complete Block Design (RCBD).

Collection of seed

The seeds of sesame variety were collected from Oil Research Center, Regional Agricultural Research Station (BARI), Ishurdi, Pabna, Bangladesh.

Test crop and its characteristics

The varieties are very popular due to its unique properties such as can be grown in the year round (*Rabi*, *Kharif*-1 and *Kharif*-2), short life span (58-60 days), high fruit yielding tall variety, fruit set in whole year, number of fruit in each adult plant 65-75, big sized fruit (1500-1700g), oblong in shape containing 55-60% oil. The variety is cultivated all over Bangladesh but very suitable in southern part of Bangladesh. The size of the seed is moderate (TSW 25-32 g), deeply yellow seed coat color, moderately resistant to yellow mosaic virus, and higher seed yield (3.0-3.3t ha^{-1}).

Land preparation and fertilizer application

The land was prepared with two ploughing, cross ploughing followed by laddering. The soil of the experimental plot was acidic with poor organic matter. The unit plot size was3 m x 2m.The plots were fertilized with urea, TSP, MOP. Half urea and all other should be applied during final land preparation. Rest urea was applied at 25 DAS.

Imposition of treatments

Various doses of sulphur *viz*. 0, 18, 24 and zinc viz. 0, 1.44, 2.88 kg/ha were applied in soil as per treatment specification during land preparation.

Sowing of seeds

The seed was sown at the rateof8 $kgha^{-1}$with required moisture condition of the plots.

Intercultural Operations

Various intercultural operations were performed for the better growth and development of the sesame after establishment of seedlings.

Irrigation and drainage

Irrigation was provided with a watering can to each plot in the evening as per necessary. Excess or stagnant water was effectively drained out for the proper growth and development of Sesame plant.

Weeding and thinning

For the insurance of better growth and development, first weeding was done at 20 DAS and 2nd weeding was done at 35 DAS.

Plant protection

The plots were infested by caterpillar, which was successfully controlled by applying *Ripcord* (15g/L *Cypermethrin*) with two times hand spraying @ 20 ml/500ml of clean water.

Data Collection

The data was collected at 15, 30, 45 and 60 DAS from each plot. The collected samples of each plot was bundled separately, properly tagged and brought to the agronomy laboratory. The following parameters were taken.

Plant height

Plant height was measured from the base of the plant to the top of the plant at 15,30 and 60 DAS. From each pot three plant samples were taken and means were calculated.

Fresh weight of leaves, petioles, stems, reproductive organs and roots

Fresh weight of leaves, petioles, stems, reproductive organs and roots were measured in each plot and calculated the average value.

Dry weight of leaves, petioles, stems, reproductive organs and roots

Dry weight of leaves, petioles, stems, reproductive organs and roots were measured in each plot and calculated the average value.

Data Analysis

The data were analyzed by the MSTAT-C program with the help of computer.

These data are in agreement with other studies reporting the increased activity of antioxidant enzymes in faba bean in response to drought stress [55, 54, 56].

These results are consistent with previously reported data for faba bean, where drought tolerant genotypes accumulate more proline than sensitive genotypes [55, 56], even if nodule proline content was not evaluated

Results and Discussion

Plant height

The plant height of sesame was significantly influenced by the application of sulphur and zinc fertilizer at different growth stage. The longest plant height (185 cm) was recorded at the application of sulphur (18 kg ha^{-1}) and zinc (1.44 kg ha^{-1}), while the smallest (135.2 cm) was recorded from the treatment combinations of S_1Zn_1 during harvesting stage (Table 3). Similar

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trends were observed at different growth stage of sesame. The results are consistent with the previously reported information of Jauhari et al. (2005), Jia and Gray (2008), and it synergistically improved the crop performance i.e. increased the growth and development and thereby increased the plant height under normal and stress conditions of sesame. Sulphur generally tends to increase plant height and it might be enhance cell division, elongation, and expansion resulting increased plant height. The reduced plant height due to shortening of internodes and leaves in Zn deficient plants is consistent to the study of Mortvedt et al. (1999), whereby there was a decrease in plant growth hormones, when Zn was insufficient in sesame plot.

Table 3: Effect of sulphur and zinc on the plant height of sesame at different DAS

Treatment combinations	**Plant height (cm)**		
	35 DAS	**45 DAS**	**60 DAS**
T_1 (S_1Zn_1)	8.07f	55.50	135.20d
T_2 (S_1Zn_2)	12.47cd	71.67	150.36b
T_3 (S_1Zn_3)	10.11e	64.80	142.50c
T_4 (S_2Zn_1)	13.00d	75.50	156.76c
T_5 (S_2Zn_2)	17.85a	98.80	185.00a
T_6 (S_2Zn_3)	14.28b	84.21	167.50b
T_7 (S_3Zn_1)	8.27ef	70.30	149.53cd
T_8 (S_3Zn_2)	12.70bc	78.60	169.40b
T_9 (S_3Zn_3)	10.08cd	65.33	161.43c
LSD	0.112*	NS	2.72*
CV (%)	19.86	6.35	3.26

S_1= 0 kgha^{-1}, S_2= 18 kgha^{-1}, S_3= 24 kgha^{-1}; Zn_1=0 kgha^{-1}, Zn_2=1.44 kgha^{-1}, Zn_3=2.88 kgha^{-1}

Fresh weight of different plant parts

Leaves weight

The application of sulphur and zinc had the positive effect on the leaves weight of sesame at various growth stages (Table 4). The treatment combination of S_1Zn_1 (0 + 0 kgha^{-1}) and S_2Zn_2 (18 kg S + 1.44 kg Zn ha^{-1})produced the minimum (0.39, 9.30 and 15.43 g plant^{-1}) and the maximum leaves weight (1.18, 25.95 and 31.06 g plant^{-1})at 35, 45 and 60 DAS, respectively among all treatment combinations (Table 4). Application of sulphur @ 30-40 kg ha^{-1} significantly increased the leaf area index (LAI) at all growth stages of sesame, which tends to increase leaves weight in sesame (Ramakrishna, 2013). These results can be explicated by the fact that the use of S enhances chlorophyll formation. Cakmak (2008) who reported that Zn

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fertilizer enhanced plant growth hormones and enzyme systems which lead to maximize the plant growth which is in general agreement with the present findings.

Table 4: Effect of sulphur and zinc on the fresh leaves weight of sesame at different DAS

Treatment combinations	Fresh leaves weight (g)		
	35 DAS	**45 DAS**	**60 DAS**
T_1 (S_1Zn_1)	0.39f	9.30d	15.43d
T_2 (S_1Zn_2)	0.71cd	14.17c	22.65b
T_3 (S_1Zn_3)	0.51e	11.45cd	18.60c
T_4 (S_2Zn_1)	0.65d	13.35c	19.13c
T_5 (S_2Zn_2)	1.18a	25.95a	31.06a
T_6 (S_2Zn_3)	0.86b	18.36b	25.04b
T_7 (S_3Zn_1)	0.47ef	10.11d	17.25cd
T_8 (S_3Zn_2)	0.78bc	16.92bc	23.59b
T_9 (S_3Zn_3)	0.69cd	12.03cd	19.34c
LSD	0.15*	0.39*	0.79*
CV (%)	9.62	20.42	6.25

S_1= 0 kgha^{-1}, S_2= 18 kgha^{-1}, S_3= 24 kgha^{-1}; Zn_1=0 kgha^{-1}, Zn_2=1.44 kgha^{-1}, Zn_3=2.88 kgha^{-1}

Stems weight

The stem weight of sesame provided the significant variation at various growth stages by the application of sulphur and zinc. At 60 DAS, the highest stem weight (89.85 g) was found at treatment combinations of S_2Zn_2 whereas the lowest (37.73 g) was recorded at S_1Zn_1 among all of the treatment combinations (Table 5).

Table 5: Effect of sulphur and zinc on the stem fresh weight of sesame at different DAS

Treatment combinations	Stem fresh weight (g)		
	35 DAS	**45 DAS**	**60 DAS**
T_1 (S_1Zn_1)	0.27c	21.94	37.73c
T_2 (S_1Zn_2)	0.53abc	31.53	55.07b
T_3 (S_1Zn_3)	0.40bc	26.05	41.08bc
T_4 (S_2Zn_1)	0.37bc	34.13	51.050bc
T_5 (S_2Zn_2)	0.81a	53.08	89.85a
T_6 (S_2Zn_3)	0.63ab	39.69	78.24bc
T_7 (S_3Zn_1)	0.30c	33.43	46.41d
T_8 (S_3Zn_2)	0.57abc	39.15	81.90a
T_9 (S_3Zn_3)	0.47bc	34.23	73.93a
LSD	0.06*	NS	5.35**
CV (%)	22.21	27.11	9.91

S_1= 0 kgha^{-1}, S_2= 18 kgha^{-1}, S_3= 24 kgha^{-1}; Zn_1=0 kgha^{-1}, Zn_2=1.44 kgha^{-1}, Zn_3=2.88 kgha^{-1}

Significant increase of the fresh weight of sesame plant with the application of sulphur and zinc over control has also been reported by Rajput et al. (2003) and Barsabindu (2015). Many

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scientists recommended that the use of S through gypsum along with chemical fertilizer can ensure the higher uptake of N owing to strong synergistic interaction between the available N and S status in soil resulting increased plant growth of sesame (Mondal et al., 2012; Ramakrishna, 2013).

Roots weight

Application of sulphur and zinc progressively influenced the root weight of sesame at different days after sowing. The highest root weight (26.37 g) and lowest root weight (7.17 g) of sesame were found from the treatment combinations of S_2Zn_2 and S_1Zn_1, respectively among all treatment combinations at 60 DAS (Table 6). Similar trends were also observed at 35 and 45 DAS. This result reconfirms with the results of Salwa et al. (2010) in sesame and Rajput et al. (2003) in *Tagetes minuta*.

Table 6: Effect of sulphur and zinc on the root fresh weight of sesame at DAS

Treatment combinations	Root fresh weight (g)		
	35 DAS	45 DAS	60 DAS
T_1 (S_1Zn_1)	0.07c	2.51f	7.17i
T_2 (S_1Zn_2)	0.19bc	5.02cd	11.38e
T_3 (S_1Zn_3)	0.12bc	3.62ef	10.20f
T_4 (S_2Zn_1)	0.11bc	4.79cde	8.92g
T_5 (S_2Zn_2)	0.39a	9.79a	26.37a
T_6 (S_2Zn_3)	0.18bc	5.54c	18.92c
T_7 (S_3Zn_1)	0.14bc	3.98de	7.63h
T_8 (S_3Zn_2)	0.21b	6.78b	21.50b
T_9 (S_3Zn_3)	0.17bc	5.71bc	17.05d
LSD	0.11*	1.12**	0.05**
CV (%)	18.23	8.5	9.00

S_1= 0 kgha^{-1}, S_2= 18 kgha^{-1}, S_3= 24 kgha^{-1}; Zn_1=0 kgha^{-1}, Zn_2=1.44 kgha^{-1}, Zn_3=2.88 kgha^{-1}

Effect of sulphur and zinc fertilizer on the dry weight of different plant parts

Leaves dry weight

Leaves dry weight of sesame progressively influenced due to sulphur and zinc fertilization. The highest (8.18 g) and lowest leaves dry weight (3.02 g) were found in treatment combination of S_2Zn_2 and S_1Zn_1 among all treatment combinations at 60 DAS as well as others (Table 7). The increment of the leaf area and leaf dry weight in sunflower owing to application of sulphur has also been reported by Shekhawat and Shivay (2009). Duncon (1975) reported that the leaf area index is often used as vital indicator of plant growth for evaluating assimilation and dry matter production. Alike findings have also been reported previously by Salwa et al. (2010) in sesame, and Rajput et al. (2003) in *Tagetes minuta*, who concluded that optimum supply of sulphur

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enhanced the higher production of photosynthates, which ultimately increased the plant growth and leaf dry weight.

Table 7: Effect of sulphur and zinc on the dry weight of leaves of sesame at different DAS

Treatment combinations	Leaves dry weight (g)		
	35 DAS	45 DAS	60 DAS
T_1 (S_1Zn_1)	0.03g	1.52i	3.02i
T_2 (S_1Zn_2)	0.15e	2.86f	4.79d
T_3 (S_1Zn_3)	0.09f	2.09e	3.69g
T_4 (S_2Zn_1)	0.23c	1.94g	4.15f
T_5 (S_2Zn_2)	0.43a	4.09a	8.18a
T_6 (S_2Zn_3)	0.29b	3.28c	5.45c
T_7 (S_3Zn_1)	0.19d	1.78h	3.27h
T_8 (S_3Zn_2)	0.31b	3.85b	6.78b
T_9 (S_3Zn_3)	0.23c	3.04d	4.71e
LSD	0.001**	0.02**	0.03**
CV (%)	8.70	4.62	2.81

S_1= 0 kgha^{-1}, S_2= 18 kgha^{-1}, S_3= 24 kgha^{-1}; Zn_1=0 kgha^{-1}, Zn_2=1.44 kgha^{-1}, Zn_3=2.88 kgha^{-1}

Stem dry weight

Sulphur and zinc fertilization had the positive influence on stem dry weight of sesame at various DAS. The combination S_1Zn_1 produced the lowest stem dry weight (6.56 g), while the highest (26.60 g) was recorded in S_2Zn_2 among all treatment combinations at 60 DAS as like others growth stages (Table 8). Very closer findings were also depicted by Jia and Gray (2008), Yadav et al. (2009) and Barsabindu (2015). The highest dry matter of sesame with the application of 20 kg S/ha has also been reported by Mondal et al. (2012) who concluded that sulphur fertilization increased the uptake of S and N which stimulated the biochemical activity in plants thereby increased total dry matter.

The lowest seed yield was observed in control plants with any genotype due to lack of sulphur. Furthermore, application of 24 kg S/ha decreased stem dry weight. This result is in agreement with that of Mondal et al. (2012), who reported that higher doses of S (40kg S ha^{-1}) decreased the total nitrogen accumulation in seeds due to lower biochemical activity, and resulting lower dry matter than 20 kg S ha^{-1} indicating 40 kg S ha^{-1} may be toxic for plant growth and development in sesame. Sulfur enhance biological yield which might be due to the supplementary synthesis of amino acid and chlorophyll content in growing regions, as a result increased in cell division further enhance leaf area index, height and dry matter yield (Raja et al., 2007).

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Table 8: Effect of sulphur and zinc on the dry weight of stem of sesame at different DAS

Treatment combinations	**Stem dry weight (g)**		
	35DAS	**45DAS**	**60DAS**
T_1 (S_1Zn_1)	0.02	1.81i	6.56e
T_2 (S_1Zn_2)	0.19	3.1d	15.91c
T_3 (S_1Zn_3)	0.08	2.59f	10.99d
T_4 (S_2Zn_1)	0.13	2.48g	8.29de
T_5 (S_2Zn_2)	0.33	4.81a	26.60a
T_6 (S_2Zn_3)	0.23	3.45b	19.63b
T_7 (S_3Zn_1)	0.06	2.39h	10.64d
T_8 (S_3Zn_2)	0.26	3.31c	20.5b
T_9 (S_3Zn_3)	0.17	2.92e	15.13c
LSD	NS	0.03**	0.72**
CV (%)	9.13	4.00	8.38

S_1= 0 kgha^{-1}, S_2= 18 kgha^{-1}, S_3= 24 kgha^{-1}; Zn_1=0 kgha^{-1}, Zn_2=1.44 kgha^{-1}, Zn_3=2.88 kgha^{-1}

Roots dry weight

The root dry weight in sesame significantly varied due to sulphur and zinc fertilization. At 60 DAS as like others growth stages, highest root dry weight (9.57 g) was recorded in S_2Zn_2 on the other hand, the lowest stem dry weight (2.08 g) was recorded in the combination of S_1Zn_1 among all treatment combinations (Table 9). Similar results were mentioned by Yadav et al. (2010), Cakmak (2008).

Table 9: Effect of sulphur and zinc on the dry weight of root of sesame at different DAS

Treatment combinations	**Root dry weight (gm)**		
	35 DAS	**45 DAS**	**60 DAS**
T_1 (S_1Zn_1)	0.02f	0.67e	2.08f
T_2 (S_1Zn_2)	0.15bcd	1.19cd	5.94d
T_3 (S_1Zn_3)	0.09def	0.85e	2.91f
T_4 (S_2Zn_1)	0.06ef	0.95de	4.01e
T_5 (S_2Zn_2)	0.32a	1.98a	9.57a
T_6 (S_2Zn_3)	0.22b	1.54b	6.9c
T_7 (S_3Zn_1)	0.04f	0.89e	3.81e
T_8 (S_3Zn_2)	0.13cde	1.49b	7.82b
T_9 (S_3Zn_3)	0.18f	1.29c	6.27d
LSD	0.01**	0.07**	0.21**
CV (%)	8.59	9.20	6.80

S_1= 0 kgha^{-1}, S_2= 18 kgha^{-1}, S_3= 24 kgha^{-1}; Zn_1=0 kgha^{-1}, Zn_2=1.44 kgha^{-1}, Zn_3=2.88 kgha^{-1}

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Number of branches plant^{-1}

Sulphur and zinc application non-significantly varied the number of branches plant^{-1} of sesame. At 45 DAS, the maximum and minimum number of branches plant^{-1} was recorded from the treatment combinations of S_1Zn_1 and S_2Zn_2, respectively among all treatment combinations (Table 10). Similar traits were found by Yadav et al. (2009), Salwa et al. (2010) and Barsabindu (2015).

Number of capsules plant^{-1}

The number of capsules plant^{-1} of sesame was greatly varied by applying sulphur and zinc at 45 DAS. Regarding sulfur levels, capsules plant^{-1} linearly increased with increasing sulfur levels and the highest capsules plant^{-1} were observed in plots fertilized with 18 kg ha^{-1} sulfur as compared to other treatments (Table 10). Similar results are reported by who reported significant increase in number of capsules plant^{-1} of sesame with increase in sulfur levels (Heidari et al., 2011). Among all treatment combinations, the maximum number of capsules per plant (73) was recorded in S_2Zn_2 and S_1Zn_1 produced the minimum (32.33) at 45 DAS (Table 8). Our findings are in related with the observations of Jia and Gray (2008), Yadav et al. (2009), Salwa et al. (2010) and Barsabindu (2015) who reported that S along or withcombination of Zn remarkably increased thenumber of capsules per plant in sesame.

Table 10: Effect of sulphur and zinc on the fresh weight of different plant parts of sesame at 45 DAS

Treatment combinations	45 DAS		
	Number of Branches	Number of capsules	Capsules weight (g)
T_1 (S_1Zn_1)	3.60	32.33e	18.16g
T_2 (S_1Zn_2)	3.73	53.66b	38.17c
T_3 (S_1Zn_3)	3.65	38.33de	28.09e
T_4 (S_2Zn_1)	3.63	43.33cd	24.83f
T_5 (S_2Zn_2)	4.33	73a	49.08a
T_6 (S_2Zn_3)	4.00	55b	31.85d
T_7 (S_3Zn_1)	3.80	49.66bc	37.62c
T_8 (S_3Zn_2)	4.07	68.33a	43.26b
T_9 (S_3Zn_3)	3.89	41.66d	29.26de
LSD	NS	1.56**	0.73**
CV (%)	8.96	5.35	3.74

S_1= 0 kgha^{-1}, S_2= 18 kgha^{-1}, S_3= 24 kgha^{-1}; Zn_1=0 kgha^{-1}, Zn_2=1.44 kgha^{-1}, Zn_3=2.88 kgha^{-1}

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Capsule weight

The capsule weight of sesame was remarkably varied by sulphur and zinc applications. The highest (49.08 g) and lowest capsule weight (18.16 g) were found from 18 kg S ha^{-1} + 1.44 Zn $kgha^{-1}$ and 0 kg S ha^{-1} + 0 Zn $kgha^{-1}$ among all treatment combinations at 45 DAS (Table 10). This result is general agreement with the findings of Barsabindu (2015).

CONCLUSION

The application of sulphur + zinc@ 18 kg ha^{-1} + 1.44 kg ha^{-1} produced the superior fresh weight in different parts (leaves, stem and root) of sesame among all treatment combinations. The highest amount of dry weight as well as dry matter produced by the application of sulphur + zinc@ 18 kg ha^{-1} +1.44 kg ha^{-1} among all fertilizer combinations. Higher yield components viz. capsules $plant^{-1}$ and capsule weight of sesame was produced by the application of sulphur + zinc @ 18 kg ha^{-1} + 1.44 kg ha^{-1} among all fertilizer combinations, respectively.

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