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RESEARCH PAPER

Influence of zinc sulphate on flowering and seed production of flax (*Linum usitatissimum* L.): A medicinal flowering plant

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Abstract

Soil pH less than 7 and non-availability of organic matters effects the availability of Zinc (Zn) in the soil. Due to the deficiency of Zn, a plant possibly becomes yellow and led to senescence causing chlorotic dieback. Therefore, an experiment was carried out to investigate the effects of foliar application of zinc sulphate on flowering and seed production of flax. Various concentrations of Zinc Sulphate i.e., 0.5%, 1.0%, 1.5% and 2.0% were applied at various times i.e., 40, 50, 60 days after sowing. The experiment was laid out in Randomized Complete Block Design (RCBD) with split plot arrangement having two factors, repeated three times. The results revealed that both the zinc sulphate concentrations and application time significantly influenced the growth and flowering variables of flax. Maximum value of plant height (79.6cm), stem diameter (4.4mm), number of tillers plant^{-1} (12.6), number of branches plant^{-1} (35.3), days to flowering (76.7), number of flowers plant^{-1} (252.3), number of capsule plant^{-1} (227.2), number of seed capsule^{-1} (8.2), 1000 seed weight (8.0g) were observed with 2.0% zinc sulphate application. However, application of time, 60 days after sowing resulted in maximum plant height (78.0 cm), stem diameter (4.5mm), number of tillers plant^{-1} (10.6), number of branches plant^{-1} (32.2), Days to flowering (73.3), number of flowers plant^{-1} (219.2), number of capsule plant^{-1} (189.9), number of seed capsule^{-1} (7.6) and 1000 seed weight (7.5g). It was concluded that flax plants could be sprayed at 2% zinc sulphate after 60 days of sowing for better growth and quality flower and seed production under the agro-climatic conditions of Peshawar- Pakistan.

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Introduction

Several factors affect the availability of Zn to soil but most common factors are soils which have PH> 7 and less organic matter. In such conditions, Zn deficiency could be overcome by the foliar application of zinc (Cakmak, 2008). Due to zinc deficiency, several problems occur but the most common one is Chlorotic dieback. The plant led to senescence when become yellow where zinc deficiency continues. Delay in lower nodes formation is mainly caused due to zinc deficiency (Franzen, 2004). Zn deficiency is much common in flax plant and occurs mostly in the soil having very low temperature and or high pH. This vulnerability of flax to Zn deficiency is correlated with the application of phosphorous (Jiao *et al*., 2007). Flax (*Linum usitatissimum L.*) is locally known as "Alsi", a member of linaceae family. The life span of flax plant is annual with shallow root system. Flax grows best in areas with a relatively hot weather free from frost, with adequate humidity (Dillman and Goar, 1937). Different oilseed and fibre cultivars of flax are developed (Millam *et al.,* 2005). Linum varieties are developed basically for the purpose of oil and have maximum secondary-branches and seed capsules. Flax is also utilized for fibers and showy flowers (Amit *et al*., 2010). Flax produces short fibers and long-line and it is one of the sources of industrial fibers (Van-Sumere, 1992). The omega-3 fatty-acids, mainly Docosahaxaeoic acid (DHA) developed from flax fiber, are essential compounds for nervous system and optical development in infants (Uauy *et al.,* 1996). Flax oil has an important role in blood-clotting and in control of blood-pressure (Kinsella *et al.,* 1990).

Flax is mainly cultivated through-out the Pakistan particularly in Punjab and Sindh provinces. In Pakistan several limitations affect the yield of flax crop like improper application of micro and macro nutrients, poor soil fertility and its competition with different other crops. Pakistan spends huge amount of the national economy on import of edible oil, which needs to be reduced with the production of indigenous oil crops such as flax (El-shahawy *et al.,* 2008). For this purpose, nutrient management is important. Oil seed crops not only require macro nutrients but production of quality oil can be enhanced with the application of micro nutrients (Rehm and Sims, 2006). Among these nutrients, Zinc has key role in improving yield and quality of oil seed crops (Gangloff *et al.,* 2002). Several factors affect the availability of zinc to the plants but one of the most common factors is pH, which affect zinc availability where the soil pH is more than 7. In such conditions the deficiency of zinc could be overcome by the foliar application (Cakmak, 2008). Grant *et al.* (2000) reported that different factors such as soil pH, environment, fertilizer management and cultivars are the biggest issues governing Zn uptake by flax. Several scientists have stated that the use of Zn fertilizers minimized Zn deficiency in plants (Kadar *et al*., 2003), but few scientists have associated the comparative efficacy of applying different sources of zinc to flax.Due to numerous benefits of flax an experiment with objective tofind out the influence of Zinc sulphate and time of applicationon growth, yield and quality, of flax plant.

Materials and methods

An experiment on the effect of zinc sulphate concentrations on flowering and seed production of flax (*Linum usitatissimum* L.) was carried out at Horticulture Research Farm, The University of Agriculture Peshawar (located at 34°N latitude, 71°E longitude with an altitude of 350 m above sea level and has a sub-tropical climate) during 2017-2018. The trial was laid out in Randomized Complete Block Design (RCBD) with two factors in split plot arrangements. There were two factors i.e., Zinc sulphate concentrations and Time of foliar application. Zinc sulphate concentrations were kept in subplots whereas time of its foliar application was kept in main plot. Treatments were repeated three times. All cultural practices including irrigation, hoeing, weeding, etc. were kept uniform throughout the study.

Factors studied during the study are as follow:

Factor-A (Main plot) Time of foliar application (Days after sowing)	Factor B (sub-plot) Zinc sulphate concentrations (%)
T_1 :40	C_1= 0
T_2 :50	C_2= 0.5
T_3 :60	C_3= 1.0
	C_4 = 1.5
	C5= 2.0

Studied attributes

Data were recorded on the following parameters.

Number of leaves plant^{-1}

Five plants from each treatment were selected randomly and data were recorded on the number of leaves and then their average was determined.

Plant height (cm)

Random selection of five plants from each treatment was done using measuring tape from base to the tip of the plants and their average was worked out.

Stem diameter (mm)

Digital Vernier calliper (DVC) was used for taking data on stem diameter of five randomly selected plants in all treatments.

Number of branches plant^{-1}

For number of branches of five plants from each treatment of the replications was counted and their mean was recorded.

Number of tillers plant^{-1}

For number of tillers five plants from each treatment were counted in randomly selected plants in each replications and finally their average was measured.

Days to flowering

Total number of days to flowering were counted from sowing up to initiation of flowering in five randomly selected plants in each treatment of the replications and their mean was recorded.

Number of flowers plant^{-1}

Number of flowers were counted in five plants selected randomly in each of the treatment from different replications and their average was calculated.

Number of capsules plant^{-1}

The data were recorded by counting the number of capsules in five plants selected randomly from each treatment of the three replications. Then their means were measured.

Number of seeds capsule^{-1}

Data was recorded by collecting capsules from 5 plants from each treatment and replication, threshed manually, seeds were counted and average was worked out.

1000-seeds weight (g)

From each treatment of the replications, 1000 seeds were taken and weighed in grams by digital balance.

Statistical analysis

The collected data was subjected to Analysis of Variance (ANOVA) by using randomized complete block design (RCBD) as suggested by Gilani *et al.*, 2018). For significant data, least significant difference test was applied for mean comparison by using statistical software package Statistix 8.1Inc, Tallahassee FL, USA (Basit *et al.*, 2018).

Results

Plant height (cm)

Plant height was significantly influenced by $ZnSO_4$ concentration and their time of application, whereas the interaction of $ZnSO_4$ concentration and their time of application had no significant influence on plant height of flax plant (Table 1). In case of zinc sulphate concentrations, taller plants (79.6cm) were observed when the plants were treated with 2.0% zinc sulphate, followed by the effect of 1.5, 1.0 and 0.5% zinc sulphate which produced the plants of 76.0, 73.9 and 67.8cm height respectively. Minimum plant height (63.6cm) was found in the control treatment (untreated plants) (Fig. 4). Data pertaining to time of foliar application showed that treatment of plants with zinc sulphate after 60 days of sowing resulted in taller plants (78.0cm) whereas, shortest plants (67.1cm) were observed with the application of zinc sulphate after 40 days of sowing that was statistically similar to plant height (71.5cm) when zinc sulphate was sprayed after 50 days of sowing (Fig. 1).

Stem Diameter (mm)

Application of zinc sulphate positively influenced stem diameter of flax plant, whereas time of application and combination of zinc sulphate and time of application had no significant effect on stem diameter of flax plant (Table 1). Among various zinc sulphate concentrations, maximum stem diameter (4.4mm) was produced by the plants that were sprayed with 2.0% zinc sulphate conc., followed by 1.5%, 1.0% and 0.5% zinc sulphate concentrations that produced 3.9mm, 3.8mm and 3.6mm stem diameter respectively. Minimum stem diameter (3.5mm) was recorded inplants of control plants (untreated) (Fig. 4).

Table 1. Means square of growth and yield attributes of flax as influenced by zinc sulphate concentration and time of application.

SOV	DF	Mean Square (MS)							
		PH	SD	NOTP	NOBP	DTF	NOFP	NOCP	NOSC
Replications	2	14.21^{ns}	1.00^{ns}	4.06^{ns}	157.14^{ns}	7.36^{ns}	3160.7^{ns}	1638.2^{ns}	2.5^{ns}
Time (T)	2	450.03**	5.19**	100.19**	360.26**	170.59**	18752.52**	13788.2**	8.2**
Error I	4	8.98	1.86	5.78	51.25	6.43	255.85	153.6	0.6
Concentration (C)	4	368.75**	1.19*	69.46**	293.23**	232.67**	22409.73**	21964.0**	7.4**
T×C	8	13.13^{ns}	0.18^{ns}	21.19**	11.54^{ns}	6.65^{ns}	730.41**	636.3^{ns}	0.5^{ns}
Error	24	6.59	0.30	2.20	56.15	13.28	255.36	329.4	0.3
Total	44								

PH: Plant height, SD: Stem diameter, NOTP: Number of tillers plant^{-1}, NOBP: Number of branches plant^{-1}, DTF: Days to flowering, NOFP: Number of flowers plant^{-1}, NOCP: Number of capsule plant^{-1} and NOSC: Number of seed capsule^{-1}

*=P≤0.05, **=P≤0.01, NS: Non-significant

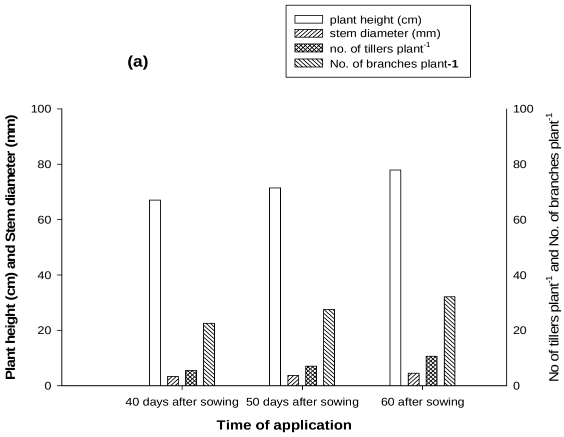

Fig. 1. Plant height (cm), Stem diameter (mm),No. of tillers plant^{-1} and No. of branches plant^{-1}as influenced by time of application of zinc sulphate concentration.

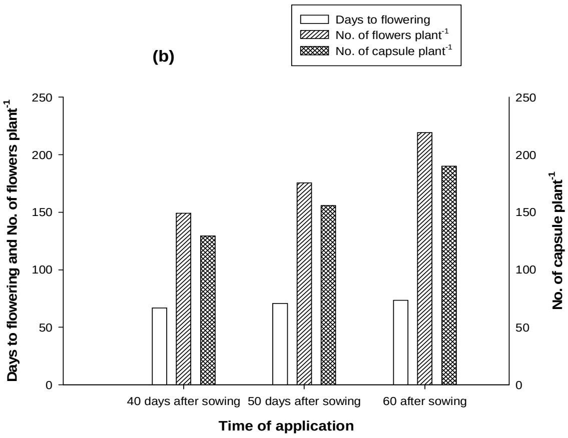

Fig. 2. Days to flowering, No. of flowers plant^{-1} and No. of capsule plant^{-1}as influenced by time of application of zinc sulphate concentration.

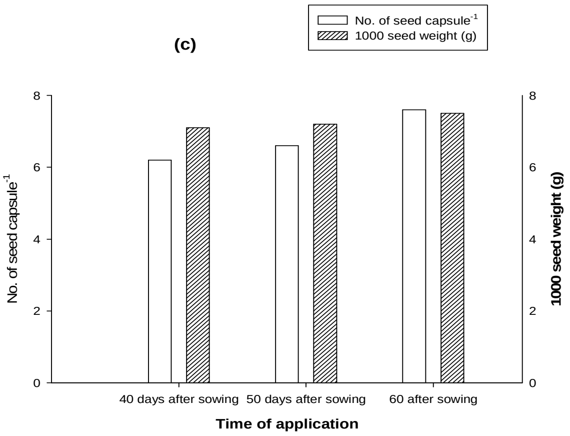

Fig. 3. No. of seed capsule^{-1}and 1000 seed weight (g) as influenced by time of application of zinc sulphate concentration.

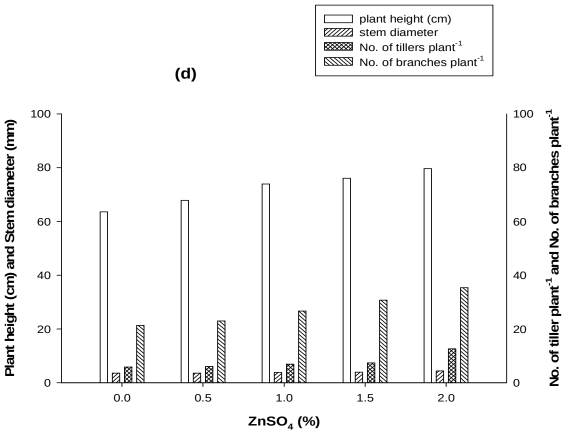

Fig. 4. Plant height (cm), Stem diameter (mm),No. of tillers plant^{-1} and No. of branches plant^{-1}as influenced by zinc sulphate concentration.

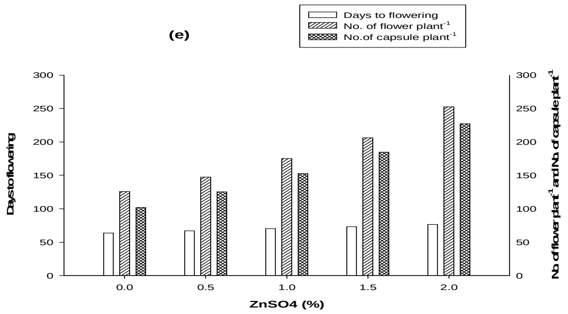

Fig. 5. Days to flowering, No. of flowers plant^{-1} and No. of capsule plant^{-1}as influenced by zinc sulphate concentration.

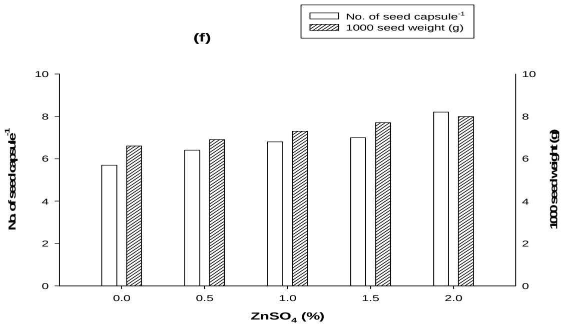

Fig. 6. No of seed capsule^{-1}and 1000 seed weight (g) as influenced by zinc sulphate concentration.

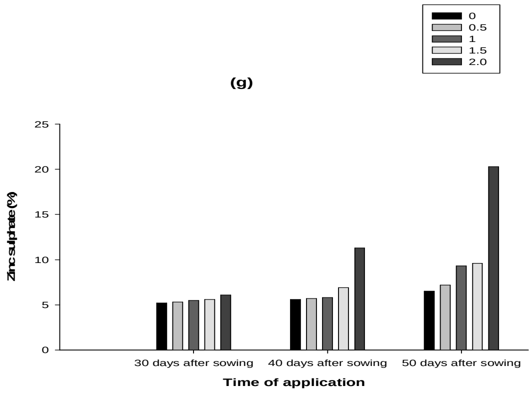

Fig. 7. No. of tillers plant^{-1} as influenced by interaction of zinc sulphate concentration and time of application.

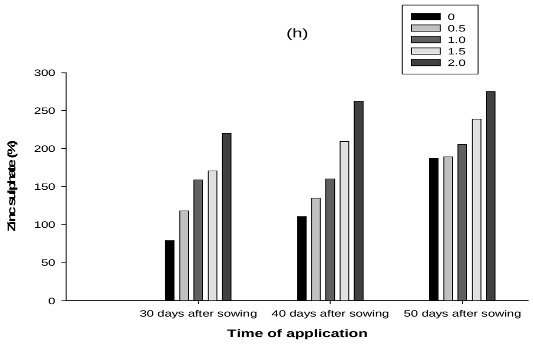

Fig. 8. No. of flowers plant^{-1} as influenced by interaction of zinc sulphate concentration and time of application.

Number of Tillers plant^{-1}

It is obvious from table 1 that application of zinc sulphate, time of application and their interaction had significant effect on number of tillers plant^{-1} (Table 1). Using various zinc sulphate concentrations, maximum tillers (12.6) were recorded in the plants treated with 2.0% zinc sulphate, followed by 1.5%, 1.0% and 0.5% zinc sulphate concentrationsthat produced 7.4, 6.9 and 6.1 tillers plant^{-1}, respectively. Minimum tillers (5.8) were observed in the plants left untreated (control plots) (Fig. 4). Regarding the time of application, more tillers (10.6) were produced by the plants sprayed with zinc sulphate after 60 days of Sowing and it was followed by 7.1 tillers produced by the plants sprayed after 50 days of sowing. However, minimum number of tillers plant^{-1} (5.5) was produced by plants treated after 40 days of sowing (Fig. 1). Data regarding interaction showed that more tillers (20.3) were produced by the plants sprayed with 2.0% zinc sulphate after 60 days of sowing. The tillers were found least (5.2) in the plants sprayed with distilled water after 40 days of sowing (Fig. 7).

Number of branches plant^{-1}

Data regarding number of branches plant^{-1} revealed that application of zinc sulphate and time of application except their interaction had a positive influence on number of branches plant^{-1} (Table 1). Number of branches plant^{-1} increased with increase in zinc sulphate concentrations. Maximum branches (35.0 plant^{-1}) were produced by the plants sprayed with 2.0% zinc sulphate, followed by 1.5%, 1.0% and 0.5% zinc sulphate concentrations that produced 30.6, 26.6 and 22.9 branches plant^{-1} respectively. Minimum branches plant^{-1} (21.3) was observed in untreated plants (Fig. 4). Maximum branches plant^{-1} (22.4) were produced by the plants sprayed with zinc sulphate concentrations after 60 days of sowing, followed by the plants sprayed after 50 days of sowing that produced (27.5) branches plant^{-1}. However, minimum branches plant^{-1} (22.4) was produced by plants sprayed with zinc sulphate after 40 days of sowing (Fig. 1).

Days to flowering

Table 1 indicated that days to flowering of flax plant was significantly influenced by zinc sulphate concentrate and their time of application.

While the interaction of zinc sulphate concentration and their time of application had non-significant effect on days to flowering (Table 1). Among various levels of zinc sulphate concentrations, Minimum days to flowering (63.6) were taken by plants in control treatment, followed by plants that received 1.5%, 1.0% and 0.5% zinc sulphate application which took 73.2, 70.3 and 67.7 days to flowering respectively. Maximum days (76.7) to flowering were recorded in plants which were sprayed with 2.0% zinc sulphate concentrations (Fig. 5). The plants sprayed with zinc sulphate concentrations after 40 days of sowing resulted in early flowering (66.6 days). This was followed by the plants sprayed after 50 days of sowing that took 70.7 days to flowering. While maximum days to flowering (73.3) were taken by plants sprayed with zinc sulphate application after 60 days of Sowing (Fig. 2).

Number of Flowers plant^{-1}

Data pertaining to zinc concentrations showed that an increase in number of flowers plant^{-1} was observed with the increase in concentration of zinc sulphate. Similarly maximum number of flowers plant^{-1} (219.2) were observed in plant treated with zinc sulphate after 60 days of sowing followed by number of flowers plant^{-1} (175.4) that was at par with number of flowers plant^{-1} noted when flax was treated with zinc sulphate after 30 days of sowing (Fig. 2). In case of Zinc sulphate concentration, maximum flowers plant^{-1} (252.3) were obtained at 2.0% zinc sulphate conc, which was closely followed by 1.5%, 1.0% and 0.5% zinc sulphate doses that produced 206.2, 174.8 and 147.3 flowers plant^{-1} respectively. Minimum flowers plant^{-1} (125.7) was recorded in control treatment (Fig. 5). Data regarding interaction between zinc concentration and application time showed that maximum number of flowers (274.8) was observed in plants sprayed with zinc sulphate at 2.0% concentration after 60 days of sowing. Minimum flowers (78.8) were produced by plants which were treated with distilled water, 40 days after sowing (Table 1, Fig. 8).

Number of Capsules plant^{-1}

Application of zinc concentration and time of application significantly influenced number of capsules plant^{-1}, whereas their interaction had a no significant influence on number of capsules plant^{-1} (Table 1). Among zinc sulphate concentrations, maximum capsule plant^{-1} (227.2) were obtained at 2.0% zinc sulphate, which was followed by 1.5%, 1.0% and 0.5% $ZnSO_4$ that produced 184.7, 152.7, and 125.2 capsule plant^{-1} respectively. Minimum capsules plant^{-1} (101.9) was noted in the untreated plants (Fig. 5). Maximum number of capsule plant^{-1} (189) was observed when flax plants were sprayed with zinc sulphate after 60 days of sowing. The Plants produced (155) capsule plant^{-1} when sprayed after 50 days of sowing. Minimum capsule plant^{-1} (129) was produced by the plants that were sprayed 40 days after sowing (Fig. 2).

Number of Seed capsule^{-1}

Data regarding zinc sulphate concentrations revealed that, the number of seed capsule^{-1} were maximum (8.2) when flax plants were sprayed with 2.0% zinc sulphate, followed by the plants treated with 1.5%, 1.0% and 0.5% zinc sulphate concentrations that produced 7.0, 6.8, and 6.4 seeds capsule^{-1} respectively. Minimum number of seed capsule^{-1} (5.7) was produced by the untreated (control) plants (Fig. 5). Maximum number of seed capsule^{-1} (7.6) was observed in the plants sprayed 60 days after sowing with zinc sulphate concentration, followed by (6.6) seed capsule^{-1} in plants sprayed after 50 days of sowing that was statistically at par with number of seed capsule^{-1} (6.2) in plants treated with zinc sulphate after 40 days of sowing (Fig. 2).

No of seed capsule^{-1}

Table 1 showed that zinc sulphate concentration and time of application had a positive influence on number of seed capsule^{-1}, whereas the interaction of zinc sulphate concentration and time of application had no positive influence on number of seed capsule^{-1} (Table 1). Comparison of treatment showed that maximum number of seed capsule^{-1} (8.2) was observedin plant treated with zinc sulphate at 2% followed by number of seed capsule^{-1} (7,6.8) noted in plants treated with zinc sulphate (1.5,1%). While minimum number of seed capsule-1(5.7) observed in control plant (Fig. 6). Similarly Fig. 3 revealed that application of zinc sulphate after 60 days had highest value of number of seeds capsule^{-1} (7.6), while minimum value of number of seed capsule-1 (6.6) were noted in plant treated with zinc sulphate after 50 days of sowing that was at par with plant applied with zinc sulphate after 40 days of sowing (6.2).

Table 2. Thousand seeds weight (g) of Flax as affected by zinc sulphate concentrations and time of application.

SOV	DF	Mean Square (MS) of 1000 seed weight (g)
Replication	2	4.0
Time (T)	2	0.6**
Error 1	4	0.1
Concentration (C)	4	2.9**
T×C	8	0.00
Error II	24	0.2
Total	44	

*=P≤0.05, **=P≤0.01, NS: Nonsignificant.

1000 Seed weight (g)

1000 seed weight (g) was significantly influenced by zinc sulphate concentration and their time of application except their interaction (Table 2). Data regarding zinc sulphate concentrations showed that highest 1000 seed weight (8.0g) was recorded in plants treated with 2.0% zinc sulphate that was statistically similar with the plants that received 1.5% zinc sulphate, which resulted in 7.7g of 1000 seed weight. While lowest 1000 seed weight (6.6g) was recorded in control treatment (Fig. 6). Average data of application time showed that highest 1000 seed weight (7.8g) in flax was observed when zinc sulphate was sprayed after 60 days of sowing, followed by the plants sprayed after 50 days of sowing (7.2g). While lowest 1000 seed weight (7.1g) of Flax flowers was observed in the plants sprayed after 40 days of sowing, though it was statistically similar to 1000 seed weight observed in plants sprayed after 50 days of sowing (Fig. 3).

Discussion

The foliar application of Zn treatments positively affected plant height, stem diameter, number of tillers plant, No. of branches, days to flowering, number of flowers plant^{-1}, number of capsule plant^{-1}, number of seed capsule^{-1} and 1000-seed weight of flax plant. Application of zinc increased plant height due to its role in biosynthesis of the natural auxin (indole acetic acid) (Mengel and Kirkby, 1987) that resulted in stem elongation (El-Shahawy *et al.*, 2008). Being a structural compound of chlorophyll, zinc has the potential to increase chlorophyll content, which eventually increases plant height (Bameri *et al.,* 2012). The current results are in relation with the findings of Omidian *et al.* (2012), whoreported that plant height increased with the application of zinc. Zincalso increased the enzymatic activity of certain enzymes which are responsible for increase in stem elongation. The current findings are also similar with that of Ambreen *et al.* (2013) who observed maximum plant height with application of zinc on gladiolus. Zinc plays important role in increasing plant height, number of capsule and branches and seed yield (Bakry *et al.*, 2012). Therefore, the increase in plant height, stem length and length of fruiting zone may be because of zinc, which play important role in the biosynthesis of the protein and oil (Omidian *et al.*, 2012), cell membrane integrity and in plant metabolism.

Zinc is essential constituent of cell component and various cell membranes that are important for the maintenance of cell structure and induce cell division, resulted in enhanced vegetative growth including stem diameter (Kendra *et al.,* 2013). The improvement in vegetative characteristics might be due to enhancement in vegetative growth which is likely to be responsible for more accumulation of photosynthetic materials, hence resulted in an increase in stem diameter. El-Shahawy *et al.* (2008) observed the significant effect of zinc on stem elongation in flax. Bordiemi and Bodi (1966) also found that number of leaves were increased with foliarapplication of Zn, which may have increased photosynthetic activity and might be responsible for the increase in diameter of stem. Nasiri *et al.* (2010) investigated that foliar zinc application has positive effect on both stem diameter and flowering. The present results are in line with Mathpal *et al.* (2015), Bharti *et al.* (2013) and Imran *et al.* (2015).

Zinc sulphate used as a foliar application increased the tillers number in the plants, which might be due to the role of zinc in synthesis and activation of various precursors and plant growth regulators.

Carbonic anhydrase enzyme is increased by zinc which plays role in metabolism of carbohydrates and morphological traits and eventually increases number of tillers (Hemantaranjan and Grag, 1988; Vankhadeh, 2002). Potanna (2017) also reported that in pearl millet, zinc application increased tiller numbers. The findings of Römheld (2001) mentioned that zinc deficient plants resulted in poor growth and least number of tillers.

The zinc sulphate increased the number of branches per plant that might be due to foliar spray of zinc sulphate causing more vegetative growth, improvement of metabolic functions and plant height, thus resulted in high number of branches as observed by Ibrahim *et al.* (2007) in bean and Yadav *et al.* (2009) in sesame. In tomato plant the foliar application of Boron and zinc in combination have a significant effect on the development of number of branches (Basavarajeshwari *et al.*, 2008), which support the present research. Number of branches is related with meristematic tissue, while zinc has a key role in the meristematic tissue development because of its role in cell division (Anonymous, 1995). Denre (2014) reported that combined application of zinc and boron had positive impact on branches plant^{-1} in pepper. The number of branches plant^{-1} was maximum due to foliar spray with the zinc, which was reported to control the hormonal balancing of the plant (Coke and Whittington, 1968). The current study is in line with Pandy and Sinha (1978) who observed that number of branches increased due to combine effect of Zn and potassium on flax plant.

Maximum number of days to flowering was noted in flax plants treated with higher concentration of zinc. Zinc has the capacity to increase the photosynthetic compound inside the plant body due to which minimum leaf drop occur and showed strength for their persistence. The results are in contrast with Singh *et al.* (1975), who observed that the foliar application of both boron and zinc in combination reduced the leaf drop because both has the ability to increase leaves numbers and thus hastened papaya flowering. Micronutrients like zinc, manganese and iron are responsible for storage of carbohydrates through photosynthesis due to this reason these three micronutrients have positive effect on days to flowering in plants (Sahu, 2016). The similar results were reported by the Jadhav *et al.* (2005) in Gerbera. Zinc delay the flowering which might be due to zinc role as an essential constituent of cell component and various cell membranes that are important for the maintenance of cell structure and induce cell division, resulted in enhanced vegetative growth (Kendra *et al.,* 2013).

Application of zinc relieved the plants from chlorosis and produced healthy green leaves which lead to enhanced photosynthetic activity and partitioning to the flower growth which may in turn increased the flower production (Nath and Biswas, 2002; Pal *et al.*, 2016). The present study is in accordance with the results of Jat *et al.* (2012), who stated that number of flowers is directly related to the number of branches and Zinc levels, which activated the enzyme and increased the numbers of branches and resulted in more flowers. Parmar *et al.* (2014) reported that increased in flowers numbers with application of zinc is due to role of zinc in photosynthetic and other metabolic activity which resulted into in different plant metabolites which are responsible for cell elongation and division. The present results are also in conformation with those of Balakrishnan (2001). Zinc and Fe in combination also play a role in production of flowers because Zinc is involved in synthesis of growth promoter hormones, process of photosynthesis and nitrogen metabolism (Marschner, 1995).

Increase in numbers of capsule in present research work under various zinc levels might be due its role as a cofactor of many enzyme, involvement in pollen function, fertilization, chlorophyll production and increased photosynthesis (Pandey *et al.*, 2006). The current results are also in agreement with Sawan *et al.* (2001) and Amberger (1974), who also reported that application of zinc increased the number of capsules in cotton plant. Pandy and Sinha (1978) reported that combination of K and zinc may have positive role on capsule number because both the nutrients has vital role in synthesis of nucleic acid, chlorophyll and translocation of photo-assimilates.

The current findings showed that foliar application of zinc sulphate increased the number of seed per capsule. The present findings are supported by Cakmak (1999), who stated that zinc has the potential to increase seed yield because of its role in increasing leaf area and photosynthesis rate. Increase in seeds per capsule might be due the key role of zinc in biosynthesis of tryptophan which is the precursor of auxins, and also presence in phosphoenolpyruvate carboxylase structure. Foliar application of zinc sulphate has the potential to increase seed yield due to its important role in physiology of plant (Alloway, 2004). Zinc is important element of plant enzymatic system such as superoxide dismutase and also responsible for auxin production, which is plant growth hormone and plays important role in protein synthesis and for seed setting. These results are in agreement with Singh *et al.* (1975) who noticed that, zinc had positive effect on seed yield of canola. These results were also in line with the results reported by El-Gazzar *et al.* (1979).

The present results revealed that increase in zinc levels enhanced seed weight. The current findings are in agreement with El-Sweify *et al.*, (2006), who stated that 1000 seed weight were enhanced by foliar application of zinc on flax. Maximum mobilization of photosynthates to developing seed by application of micronutrient might be the reason for increase in seed weight (Swain, 2015). The increase in 1000-seed weight of crop plants due to zinc might be due to its mobility through phloem from roots, stem, leaves and developing grains (Rengel, 2001). Bybordl and Mamedov (2010) reported that Zinc play key role in biosynthesis of the plant growth regulator, carbohydrate and nitrogen metabolism, which contain proteins and nucleic acids leads to enhanced accumulation of assimilate in seeds and thus resulting high seed yield. The results of this study are in line with the findings of several early workers in respect of this particular trait in various crops (Rahman *et al.*, 1996; Patel *et al.*, 2003 and Galavi *et al.*, 2012).

Conclusions

It was concluded from the research findings that among Zinc sulphate concentrations, the application of zinc sulphate at 2% concentration resulted in increased plant height, stem diameter, numbers of tillers plant^{-1}, branches plant^{-1}, with maximum days to flowering, number of flowers, capsules plant^{-1}, seeds capsule^{-1} and thousand seeds weight. Finding pertaining to time of application showed that foliar application of zinc sulphate on Flax plants 60 days after sowing resulted in increased plant height, stem diameter, numbers of tillers, branches, leaves with maximum days to flowering, number of flowers, number of capsules, number of seeds capsule^{-1} and thousand seeds weight. Interaction between Zinc sulphate concentration and its time of application revealed that Zinc sulphate at 2% concentration applied after 60 days of sowing increased number of flowers and tillers to the maximum.

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