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Usage of iron foliar spray in enhancing the growth and yield of the flax plant (*Linum usitatissimum* L)

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KEYWORDS

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Growth enhancement

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ABSTRACT

The ideal growth and development of linseed plants depend on receiving the necessary nutrients during the growing season when they are grown. Flax's yield and oil content increase using a foliar spray containing micronutrients. This study aimed to determine how foliar iron (Fe) treatment affected flax yield and its constituents. The experiment was set up at the adoptive research farm Sargodha in a randomized block design and three replicates. At the capsule filling stages and bud initiation of the flax crop, foliar sprays with varying concentrations of Fe (5.5%, 4.5%, 3.5%, 2.5%, 1.5%) and without Fe (control) were administered. Sulphate of iron (Fe) was used as the source of Fe. All treatments resulted in notable enhancements in agronomic characteristics such as grain oil contents, harvest index, biological yield, number of capsule formations, technical stem length, plant height, as well as physiological

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parameters including fluorescence yield (Ft), quantum yield (YII), photosynthetically active radiation (PAR), electron transport rate (ETR), and chlorophyll contents. The results of this study suggested that the application of 3.5% to flax during the bud initiation and capsule filling stages increases the seed yield, yield attributes, and oil contents. In conclusion, foliar spray of Fe could enhance the yield of linseed crops.

1 Introduction

Linseed (*Linum usitatissimum* L.) is a highly profitable crop producing oil and fibre (Arslanoglu et al. 2022). It has higher nutritional value because it contains fat (41%), protein (20%), dietary fibres (28%), linoleic and omega-3 fatty acids, which regulate blood flow, lower cholesterol, prevent coronary complications and provides the body with anti-carcinogenic properties (Biswas and Ansari 2023). Linseed oil has a higher fatty acids rate and is used in paints, varnishes, printed inks, coating oils, and soaps due to its quick-drying properties (Hubmann et al. 2021). Pakistan's average linseed yield is meager compared to other countries, with a yield gap of up to 73 percent (Sangmesh et al. 2023). Low production is caused by cultivation on low-fertility marginal lands, inferior crop management methods, and insufficient application of micro and macronutrients (Eleni 2022). Furthermore, sandy soil, calcareous soils, Zn deficient soils and lower micro and macronutrient levels in Pakistani soils lead to severe yield losses due to deteriorating soil fertility (Sohail et al. 2021; Bisma et al. 2021; Gondal et al. 2022; 2021b;). Linseed yield can be improved in two ways, i.e., by growing the area under cultivation (horizontal production) or by applying balanced fertilizers. However, with the current land availability, expanding the breadth of agriculture is challenging. Therefore, keeping fertility high is the only option for increasing linseed output. This might be achieved by introducing higher-yielding variety crops and providing optimal crop fertilization (Jha et al. 2023).

Even though micronutrients are needed in trace amounts, these micronutrients play a significant role in improving crop growth. As evolution indicates, the consumption of micronutrients enhances the absorption of other micro and macronutrients by altering cellular physiology (Gondal et al. 2021g). Fe supplements aid in forming proteins and cell walls, promote photosynthesis and respiration, and suppress the production of auxins (Gondal et al. 2021f). Further, Fe micronutrients help maintain the chloroplast structure, enhance the rate of respiration and photosynthesis, and minimize nitrate and sulphate reductions. Besides, better micronutrient uptake also increases plants' micronutrient concentration. Both Fe and Zn serve 3essential roles in plant metabolism, without which plants would not be able to grow appropriately (Gondal et al. 2021a). These two micronutrients stimulate the plants' various metabolic, physiological and cellular processes (Alvarez et al. 2022). Such transition metals have unpaired electrons that facilitate their inclusion in oxidation-reduction responses (Zeng et al. 2022). Plants uptake these two transition metals in small concentrations. Still, they perform a critical role in nitrogen fixation, reactive oxygen species scavenging, photosynthesis, chlorophyll synthesis, electron transport chain in chloroplast and mitochondria, DNA replication and act as a cofactor for proteins. These enzymes are also involved in the metabolic processes of mitochondria and chloroplast (Palmieri et al. 2022).

Thirty percent of the world's arable land is too alkaline for optimum crop development (Tayyiba et al. 2021; Gondal and Tayyiba, 2022). This makes low Fe availability due to high soil pH one of global agriculture's most pervasive abiotic stresses. In contrast, Fe deficiency is observed almost all over the world. Further, this Fe deficiency is most prominent in alkaline/calcareous soil with naturally lower organic carbon and highly limed, salt resistant and waterlogged soils (Gondal et al. 2021b; Gondal et al. 2021a). Soil fertility also declines as a result of growing high-yield crop cultivars that demand maximal levels of macro (N, P) and micronutrients (Fe, Zn, Mg, Mn) (Zhao et al. 2011). Fe fertilization is the practical approach to fix the problems mentioned earlier and achieve good production potential. The main objective of this study is to evaluate the (a) effect of Fe on the growth and yield of linseed and (b) to determine the appropriate level of Fe concentration towards linseed crops.

2 Materials and Methods

Sargodha, where the experiment occurred, is home to an adaptable research farm. It has a semiarid climate and is located at 32°07′ N, 72°68′ E, an elevation of 189 m. During the study, average temperatures ranged from 10 to 42.8 degrees Celsius.

2.1 Experimental setup

The randomized complete block design (RCBD) was used for this research. The plot's net size was 5 m × 1.2 m. The pre-analysis of soil was done before sowing the crop to determine the soil fertility status (Chapman and Pratt 1978). The description of the imposed treatment is given in Table 1.

Seedbed was prepared before sowing by four ploughings and one planking (breakage of large clods into the smooth surface). After that, the soil was levelled using a laser and a leveler. The flax crop seed was spread on the second fortnight of November using drill sowing, and keeping the spacing between plants and rows at 30 cm

Table 1 Detail of treatments used in this study

Treatment	Descriptions
Ctrl	Control
F1.5	Fe application of 1.5%
F2.5	Fe application of 2.5%
F3.5	Fe application of 3.5%
F4.5	Fe application of 4.5%
F5.5	Fe application of 5.5%

and 10 cm, respectively, allowed for a seeding rate of 15 kg/ha. The recommended doses of nitrogen (N), potassium (K) and phosphorus (P) fertilizers (58-58-30 kg NPK/ha) were applied for the maximum growth and improvement of plants, and the sources of fertilizer were urea, muriate of potash (MOP), and single super phosphate (SSP). The N dose is split into three parts: the first part is applied before sowing, and the remaining two are applied after the first and second irrigation. Three irrigations were used during the vegetative growth period to capsule formation. The experiment consists of 6 treatments in triplicates. The treatments include control, 1.5%, 2.5%, 3.5%, 4.5%, and 5.5%, application of Fe (Table 1), and the source of Fe foliar spray was Fe sulphate. Treatments were sprayed by hand sprayer during flowering and post-capsule formation stages. The crop was harvested after 150 days after sowing. The physicochemical properties of the study are soil have been given in Table 2.

Table 2 Physicochemical properties of soil used in this study

Parameters	Values
Sand (%)	53.8 ± 0.01
Silt (%)	25.4 ± 0.02
Clay (%)	20.8 ± 0.01
pH	8.48 ± 0.12
EC (dS m^{-1})	1.91 ± 0.01
Ca^{+2}+Mg^{2+} (mmolc L^{-1})	11.8 ± 0.73
Organic matter (%)	0.68 ± 0.01
Total organic carbon (%)	0.21 ± 0.07
Available N (mg kg^{-1})	6.70 ± 0.01
Available K (mg kg^{-1})	150 ± 9.11
Available P (mg kg^{-1})	0.36 ± 0.01

EC; Electrical Conductivity, Available P; Phosphorus, Available N; Nitrogen

2.2 Estimation of plant growth

Twenty plant samples were collected randomly from each plot to estimate agronomic parameters and oil contents. All the morphological parameters were determined by adopting the same procedure used by Nofal et al. (2011). At the same time, seed oil contents were determined by following the AOAC (1980), in which Soxhlet apparatus and petroleum ether were used for extraction. The physiological parameters such as chlorophyll contents were determined by using the SPAD meter (SPAD-502 Konica, Minolta)(Pérez-Patricio et al. 2018) while electron transport reaction (ETR), quantum yield (YII), active photosynthetic radiation (PAR), fluorescence yield (Ft) were noted by using instrument MINI-PAM-II (ALZ Mess und Regeltechnik, Effeltrich, Germany).

2.3 Statistical analysis

Using Statistics 8.1, one-way factorial ANOVA was conducted on the provided data. Comparison among treatment means was made using the least significant difference test at 0.05% probability (Snedecor and Cochran 1990).

3 Results

The effects of various Fe concentrations on the linseed plant were shown to be statistically significant (P 0.05). All the foliar concentrations of Fe significantly improved the agronomic and physiological attributes of the linseed crop. Among the tested various concentrations, maximum plant height (30.3%) and technical stem length (32.4%) of linseed plants were observed in 3.5% Fe application, and the 2.5 and 1.5% followed this compared to control. Further, applications of F4.5 and F5.5% increased the 16.7% and 16.6% plant height and 11.1% and 11.3% technical stem length, respectively, compared to the control (Figure 1).

The maximum number of branches per plant (33.3%) and the number of capsules per plant (40.0%) were also recorded from the same dose of Fe (3.5%) treatment, and the Fe 2.5% followed this. The rest of the treatments are below the given decreasing order, and it was Fe 1.5% (14.3% and 30.7%) >Fe 4.5% (14.2% and 25.1%) >Fe 5.5% (7.70% and 17.2%) as shown in Figure 2.

Similarly, Fe (3.5%) application showed the best results in terms of the number of seeds per capsule (32.0%) and 1000-grain weight (38.0%) of linseed plants, followed by Fe 2.5%, Fe 1.5%, Fe 4.5% and Fe 5.5% and showing 22.7% and 23.1%, 19.0% and 18.0%, 15.0% and 15.7%, 10.5% and 11.3% higher number of seeds per capsule and 1000-grain weight respectively than the control (Figure 3).

The highest biological yield and seed yield were observed in Fe 3.5% application (31.2% and 38.1%), followed by Fe (2.5%), Fe (1.5%), Fe (4.5%) and Fe (5.5%), showing 28.7% and 34.6%, 26.9% and 26.4%, 16.7% and 20.8%, 13.2% and 18.7% higher biological yield and seed yield respectively than the control (Figure 4).

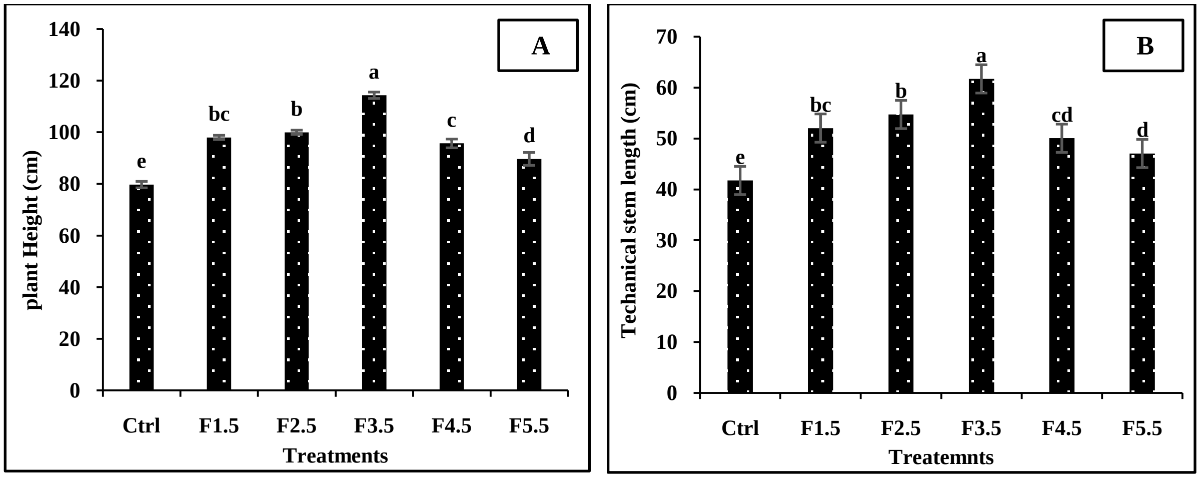

Figure 1 Impact of foliar application of Fe on (A) plant height and (B) technical stem length of linseed crop (means ± STD, n = 3); Ctrl – Control

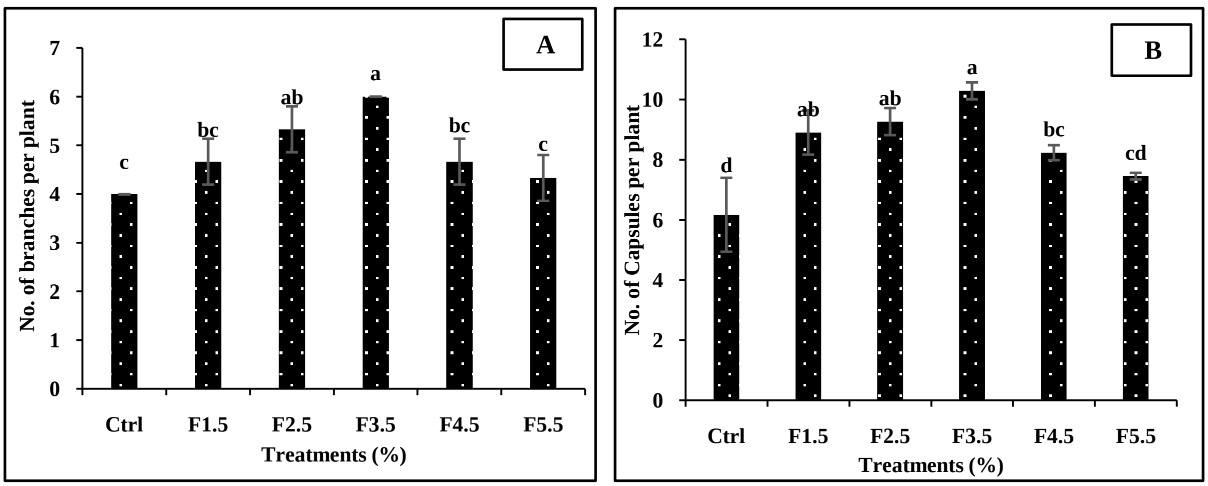

Figure 2 Impact of foliar application of Fe on (A) number of branches and (B) number of capsules per plant of linseed crop (means ± STD, n = 3); Ctrl – Control

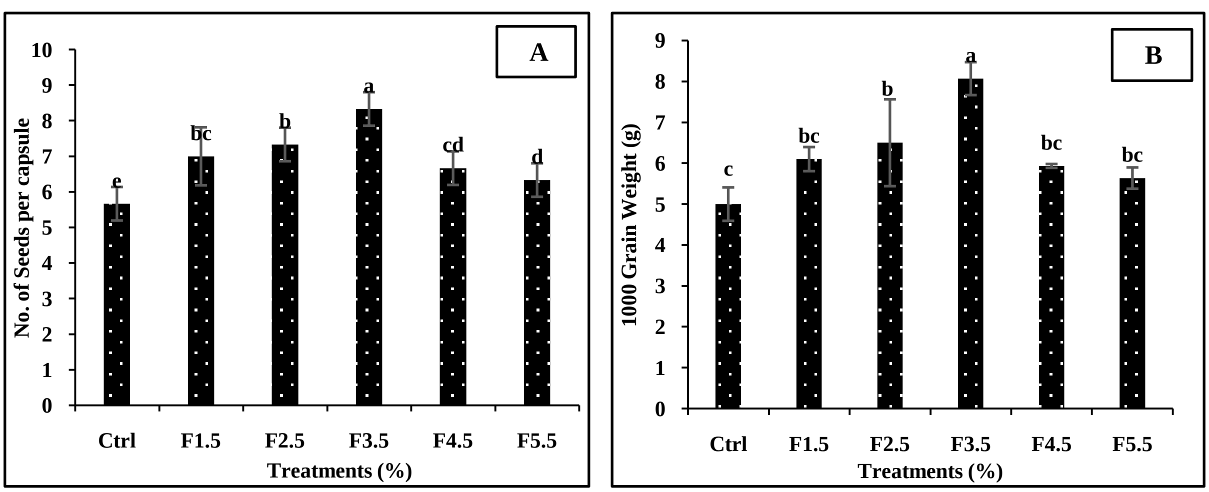

Figure 3 Impact of foliar application of Fe on (A) number of seeds per capsule and (B)1000 grain weight of linseed crop (means ± STD, n = 3); Ctrl -Control

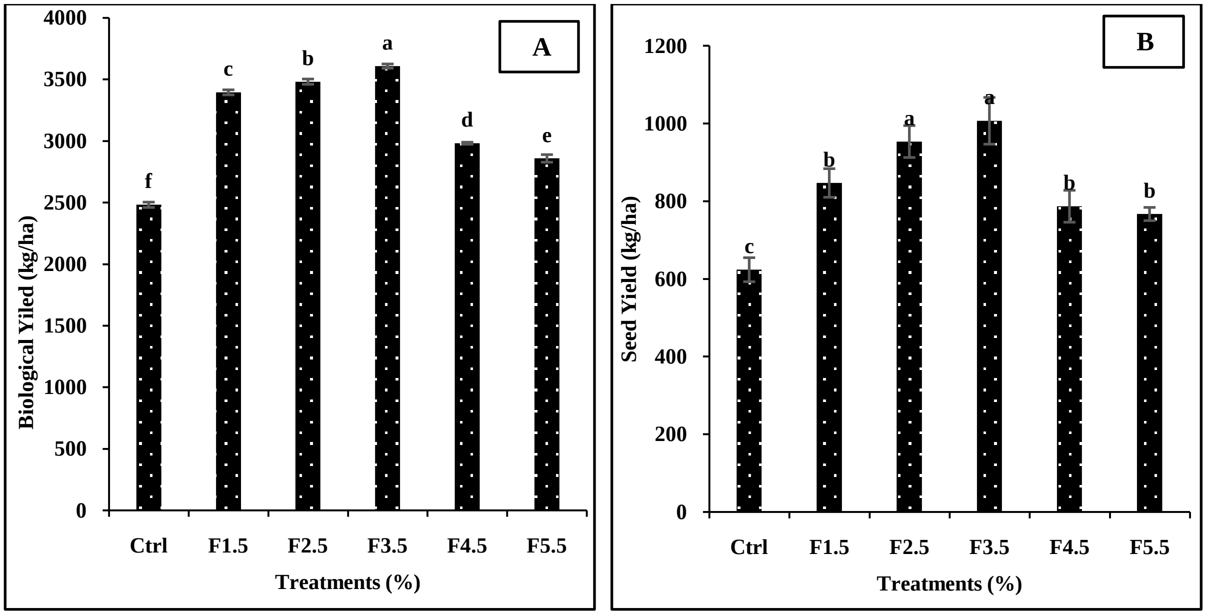

Figure 4 Impact of foliar application of Fe on (A) biological yield and (B) seed yield of linseed crop (means ± STD, n = 3); Ctrl - Control; F

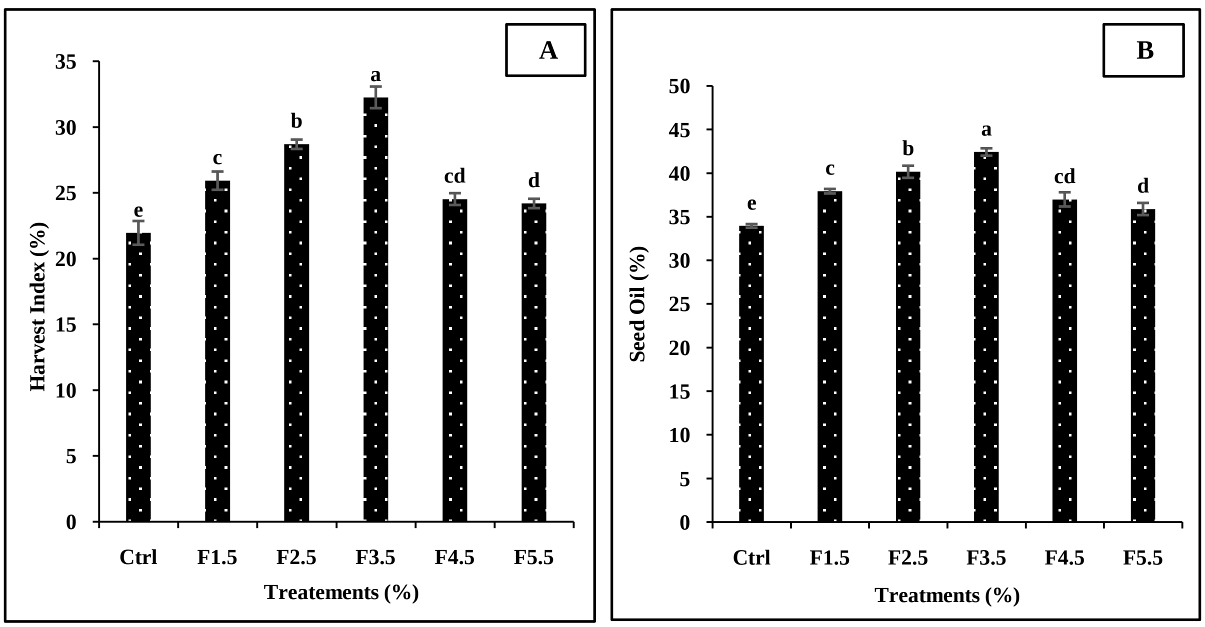

Figure 5 Impact of foliar application of Fe on (A) harvest index and (B) seed oil content of linseed crop (means ± STD, n = 3); Ctrl - Control

In the case of harvest index also, similar trends were observed, and the decreasing order in harvest index of the linseed crop was Fe 3.5% (31.9%) >Fe 2.5% (23.5%) >Fe 1.5% (15.3%) >Fe 4.5%, (10.5%) >Fe 5.5% (9.24%) as shown in Figure 5. Similarly, the Fe application significantly improved the seed oil contents of the linseed crop. The results of the study revealed that the application of Fe 3.5% showed the highest seed oil content (19.9%) followed by Fe 2.5%, Fe 1.5%, Fe 4.5% and Fe 5.5% and showing 15.4%, 10.5%, 8.20% and 5.40% seed oil content respectively than the control (Figure 5).

Like other parameters, the highest fluorescence yield (28.7%) and quantum yield (37.7%) were observed in the Fe 3.5% foliar application treatment, and this was followed by Fe 2.5%, Fe 1.5%, Fe 4.5% and Fe 5.5% and showing 23.4% and 30.3%, 17.4% and 26.1%, 14.2% and 19.5%, 10.8% and 15.8% higher fluorescence yield and quantum yield respectively as compared the control (Figure 6).

The maximum photosynthesis active radiation (43.7%) and electron transport rate (39.6%) were observed in Fe 3.5%

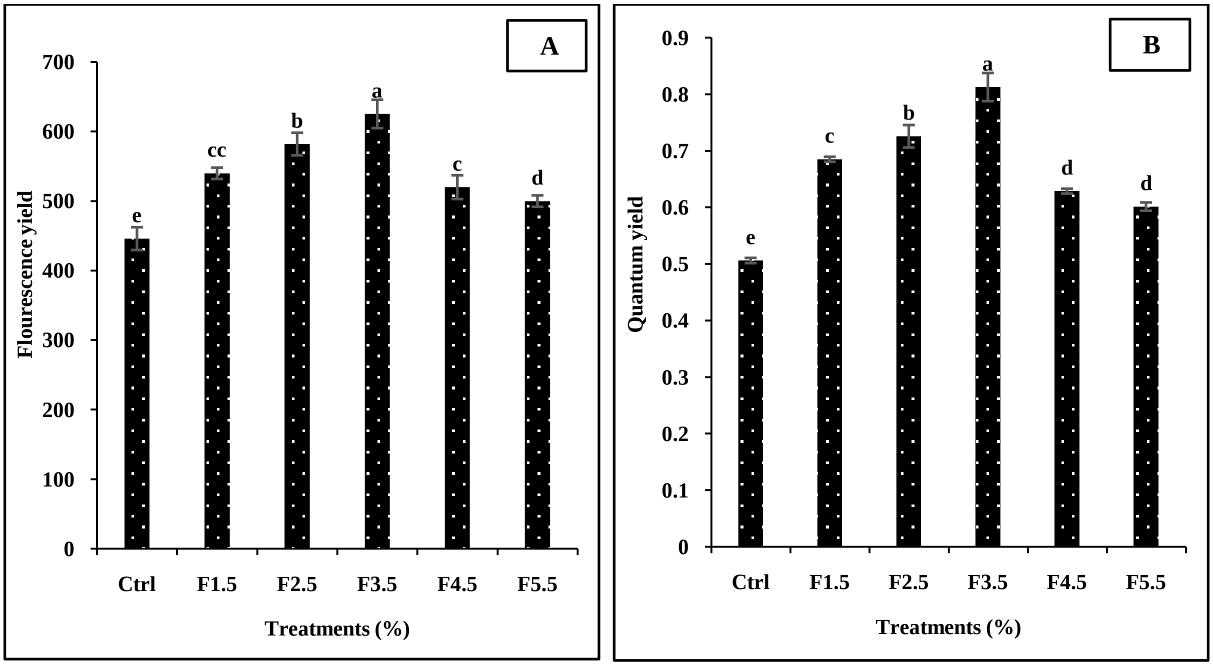

Figure 6 Impact of foliar application of Fe on (A) fluorescence yield and (B) quantum yield of linseed crop (means ± STD, n = 3); the fluorescence yield and quantum yield were taken after 70 days of sowing; Ctrl – Control

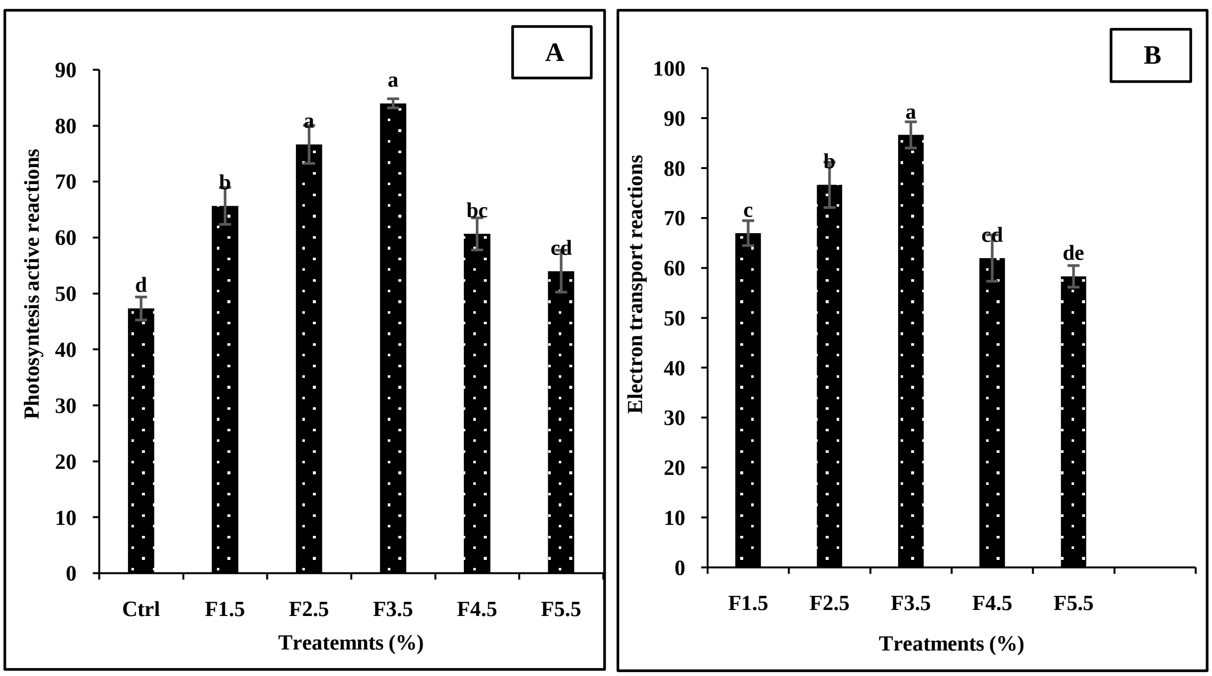

Figure 7 Impact of foliar application of Fe on (A) photosynthesis active radiation and (B) electron transport rate of linseed crop (means ± STD, n = 3). The photosynthesis active radiation and electron transport rate were taken after 70 days of sowing; Ctrl - Control; F

application treatment, followed by Fe 2.5%, Fe 1.5%, Fe 4.5%, and Fe 5.5%, which showed 38.3% and 31.7%, 27.9% and 22.0%, 22.0% and 15.6%, 12.3% and 10.3% higher photosynthesis active radiation and electron transport rate respectively than the control (Figure 7).

The maximum chlorophyll content (30.3%) of linseed plants was observed in the Fe3.5% application, followed by Fe 2.5%, Fe 1.5%, Fe 4.5% and Fe 5.5% and showing 20.3%, 18.7% 16.7% and 11.1% higher chlorophyll content as compared to the control (Figure 8).

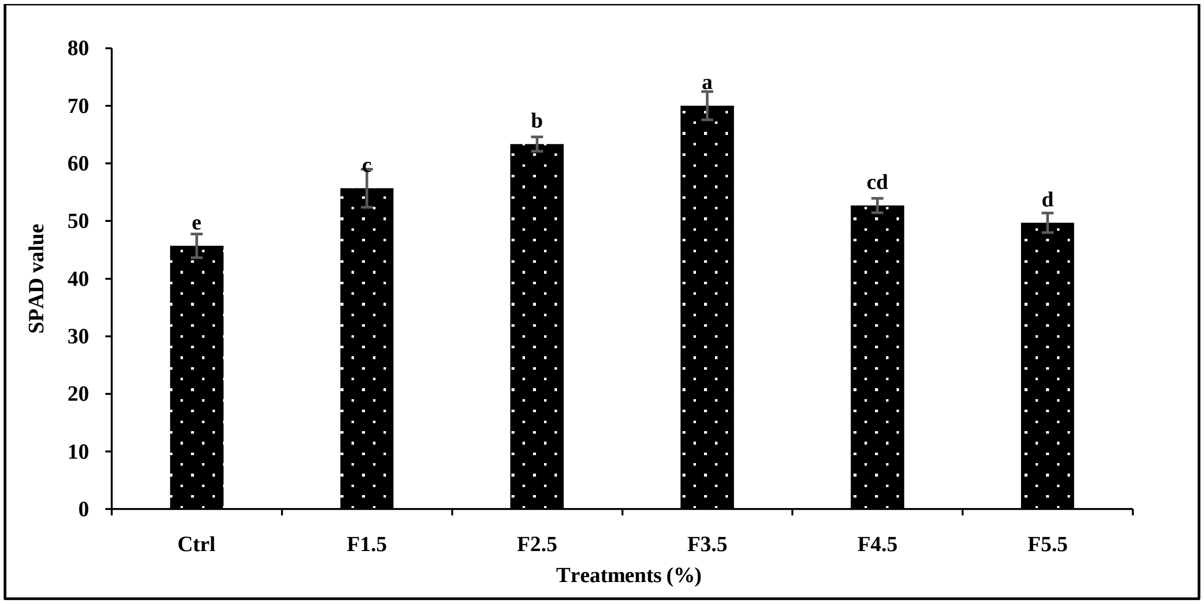

Figure 8 Impact of foliar application of Fe on chlorophyll content (SPAD value) of linseed crop (means ± STD, n = 3). The SPAD value was taken after 70 days of sowing; Ctrl – Control

4 Discussion

The current study's findings showed that the foliar application of Fe significantly improved all flax plants' physiological and agronomic attributes. It may be due to the critical role of Fe's in chlorophyll synthesis that stimulates the plant structure, improves the functions of chloroplast and enhance the rate of photosynthesis (Rout and Sahoo 2015). Furthermore, the foliar application of Fe also improves the microbial and enzymatic activities that might help enhance the physiological and agronomic attributes of linseed plant (Gondal et al. 2021c; 2021d; 2021e; 2021f; Bisma et al. 2021; Kumar et al. 2021). The results of Esmail et al. (2014) supported this study. Cynthia et al. (2004) also suggested the role of Fe and zinc-like micronutrients in activating many essential enzymes and regulatory cofactors that help plant growth and yield improvement. Similarly, Rezaei-Chiyaneh (2016) suggested that applying Fe and chelated zinc increased flax and bean growth. According to Majeed et al. (2020), Fe enhances the economic returns, yield and yield components in the mungbean; in this manner, these results agree with the present study's findings. The Khalifa et al. (2011) results corroborated our findings and suggested that seed nutrient content, yield components, yield and oil percentage all exhibited significant interactions between cultivars and micronutrient foliar treatment.

Similarly, biological yield, harvest index, and grain oil contents were also improved due to the synthesis of pigments that increase the seed index (Mengel et al. 2001). These results are consistent with the results achieved by other researchers. Straw yield and its components vary greatly between flax genotypes. These findings revealed substantial variation between cultivars of flax when grown in newly reclaimed sandy soil. These variations are likely attributable to differences in origin, growth habit, genetic diversity, and environmental variables among studied cultivars. Foliar spray of zinc, manganese, and iron increased oil and fibre production in flax plants (Grant et al. 2000; Ali et al. 2009; Bakry et al. 2012). Also, all the physiological parameters, including chlorophyll contents, were improved because Fe application creates better conditions for plant growth (Mengel et al. 2001). According to Nofal et al. (2011), applying micronutrients even in salt-affected soils enhanced the physiological parameters of flax plants. A similar finding was reported by Emam (2020). However, the foliar administration of micronutrients did not improve the seed oil content. Results of the study revealed that the best foliar application level of Fe was 3.5%. Khalifa et al. (2011) suggested that foliar spray of micronutrients has been exposed to an upsurge in seed oil and nutrient content.

Conclusions

Micronutrients are essential for increased flax growth and output but are only required in trace amounts. As much as 30 percent of the world's arable land is excessively alkaline for crop yield, making low Fe availability, and this is one of the most common abiotic stresses in global agriculture. The results suggested that Fe supplementation to the crop plant at various stages boosted plant growth, and it was successfully established with even a modest amount of Fe foliar application (1.5%), which improves the plant growth features compared to the control. The Fe supplementation at the rate of 3.5% improves flax yield and growth and can be established as a recommended dose for flax plants after more similar research.

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