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Exploring the effect of zinc and boron application on oil contents, protein contents, growth and yield of sunflower

Explorando o efeito da aplicação de zinco e boro no teor de óleo, teor de proteína, crescimento e rendimento de girassol

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Highlights

Sunflower is an important non-conventional oil seed crop.
Zinc is an important mineral playing an important role in the growth and development of plants.
Globally deficiency of boron is the second most leading micronutrient problem.

Abstract

Sunflower is sensitive to boron (B) and zinc (Zn) deficiency when grown on deficient soil, A field experiment was conducted to determine the main and interactive effects of soil applied Zn and B on total production

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of sunflower at Agronomic Research Area, University of Agriculture, Faisalabad. Experiment was laid out in randomized complete block design (RCBI) with factorial arrangement using three replications with net plot size of 6 m x 4.5 m. The soil application of variable levels of Zn (0, 10, 20 and 30 kg ha^{-1}) and B (0, 1, 2 and 3 kg ha^{-1}) in the form of zinc sulphate and boric acid, respectively were applied at time of sowing. All other agronomic and plant protection practices were kept uniform. The data regarding growth, yield and quality parameters were noted by using standard procedures. Results showed that Zn @ 20 kg ha^{-1} and B @ 3 kg ha^{-1} significantly increased the number of plants per plot at harvest, stem diameter, head diameter, number of achenes per head, 1000-achene weight, biological yield and days to maturity, achene yield kg per, harvest index, leaf concentrations or Zn at heading stage, leaf concentrations of B at heading stage (ppm), achene oil content (%), achene protein contents as compared to control. This study concluded that higher growth and yield of sunflower can be achieved by application of Zn at 20 kg ha^{-1} and B at 3 kg ha^{-1} under Faisalabad conditions.
Key words: Sunflower. Zinc. Boron. Oil and protein contents. Yield.

Resumo

O girassol é sensível à deficiência de boro (B) e zinco (Zn) quando cultivado em solo deficiente. Um experimento de campo foi conduzido para determinar os efeitos principais DA interação Zn e B aplicados no solo na produção total de girassol na Área de Pesquisa Agronômica, Universidade de Agricultura, Faisalabad. O experimento foi realizado em delineamento de blocos completos casualizados (RCBI), com arranjo fatorial, utilizando três repetições e parcelas de 6 m x 4,5 m. A aplicação no solo de níveis variáveis de Zn (0, 10, 20 e 30 kg ha^{-1}) e B (0, 1, 2 e 3 kg ha^{-1}) foi aplicada em época da semeadura na forma de sulfato de zinco e ácido bórico, respectivamente. As práticas agronómicas e de proteção fitossanitária foram mantidas uniformes. A aplicação de 20 kg ha^{-1} de Zn e 3,0 kg ha^{-1} de B aumentaram o número de plantas por parcela na colheita, diâmetro do caule, diâmetro da cabeça, número de aquênios por cabeça, peso de 1000 aquênios, rendimento biológico e dias até a maturidade, rendimento de aquênios, índice de colheita, concentrações foliares de Zn no estágio de espigamento, concentrações foliares de B no estágio de espigamento, teor de óleo de aquênio, aquênio conteúdo de proteína em comparação com o controle. O maior crescimento e rendimento do girassol podem ser alcançados pela aplicação de Zn a 20 kg ha^{-1} e B a 3 kg ha^{-1} nas condições de Faisalabad.
Palavras-chave: Girassol. Zinco. Boro. Conteúdo de óleo e proteína. Rendimento de grãos.

Introduction

Pakistan has been facing the shortage of edible oil that can hardly to fulfill the demand. Consumption of edible oil is more than production, so we have to increase the amount of edible oil in order to fulfill the requirement of an ever increase in population. During 2013-14, total edible oil consumption was 2.35 million tons in Pakistan whereas our total production was only 0.612 million tons (which is only about 26% of total requirement) remaining 1.738 million tons (which is 74% of total requirement) was fulfilled through imports. Pakistan has spent 153.3 billion rupees on importing of edible oil during 2013 (Mujeeb-ul-Haq et al., 2020). Therefore, there is a dire need to increase our production to save the out plow of national economy. Sunflower (*Helianthus annuus* L.)

is an important non-conventional oil seed crop which belongs to the Compositae family playing a vital role in vegetable oil industry in the world because it is one of the major world's sources of vegetable oil. Sunflower is the third oilseed crop (world ranking) on the production of total oil seeds after groundnut and soybean (Mujeeb-ul-Haq et al., 2020; Ramulu et al., 2011). Cultivation of sunflower has become common because it can be cultivated twice a year with 90-120 days of short maturity period.

In Pakistan edible oil is mainly obtained from traditional oilseed crops (i.e., sesame, linseed, rapeseed and mustard etc.) and non-traditional sources (i.e., sunflower, soyabean and safflower), In this scenario, sunflower has a greater potential to fulfill the gap between consumption and production (Mujeeb-ul-Haq et al., 2020; Badar et al., 2002). Sunflower achene contains 20-27% protein and 40-47% oil contents (Saleem et al., 2003). Sunflower oil is a rich source of vitamins A, D, E and K having polyunsaturated and saturated fatty acids. It contains linoleic acid 71.9% with high percentage of 59.9% polyunsaturated fatty acids and oleic acid 16.2% (Rathore, 2001). Sunflower oil is used for different purposes like cooking etc. Its highly nutritive seed cake is used for cattle feed due to presence of balanced amino acids and greater amount of protein (Mujeeb-ul-Haq et al., 2020; Gandhi et al., 2008).

Proper growth and development of micronutrients has a specific role in deficiency and toxicity in growth (Adnan et al., 2020; Imtiaz et al., 2010). The micronutrient% of grain arc also improved by the application of balanced micronutrients in addition to increase the yield (Waheed et al., 2021; Adnan et al., 2020). About half population of the world or more is affected by micronutrients, deficiency mostly children and women in developing countries (T. Ahmed et al., 2012). Yield of crop and health of humans and animals can seriously disturbed by the deficiency of micronutrients (Malakouti, 2008). Sunflower is more responsive to micronutrients. Among all the micronutrients, zinc (Zn) is deficient in an extensive range of soils particularly in calcareous soils. Panhwar et al. (2011) described that there is deficiency of Zn in Pakistani soils and Zn deficit is considered third most crop nourishment problem in Pakistan standing after deficiency of N and P. Imbalanced application of nutrients in calcareous soils may cause decrease Zn supply power of soil (Rashid & Ryan, 2004). Zinc (Zn) is an important mineral playing an important role in the development of humans, animals, and plants. Zn also gives good results in production of biomass (Adnan et al., 2020; Cakmak, 2008). Calcareous soils are much deficient (<0.5 mg kg^{-1}) in zinc (Rafique et al., 2006).

Boron was found deficient (<0.5 mg kg^{-1}) in 48% of arable soils of Punjab (Niaz et al., 2002). Cotton and wheat growing areas of Pakistan are deficient in available B (Abid et al., 2002). Boron is an important component of cell walls. Boron deficiency retards the root elongation and diminishes the concentrations of macronutrients such as phosphate or potassium without disturbing the nitrate as well as micronutrients such as magnesium or calcium (Camacho-Cristóbal et al., 2005). Boron (B) is also helpful for the healthy growth of plants. Globally deficiency of boron is the second most leading micronutrient problem (Alloway, 2008). Boron deficiency symptoms (necrosis of upper leaves and hardening) are observed in newly formed tissues due to the immobility of B in phloem (Epstein & Bloom, 2005). The rate of photosynthesis decreases due to deficiency or toxicity of B which also causes lower chlorophyll levels (Bolaños et al., 2004). Calcareous soils of Pakistan where rice and wheat are grown are deficient in available boron, yield and yield contributing factors of rice and wheat are increased with boron application (Rashid & Ryan, 2004, 2008). The main objective of this research was to determine the main and interactive effects of soil applied Zn and B on yield and quality of sunflower while the second objective was to determine Zn and B rates that increase yield, yield related attributes and quality of sunflower.

Materials and Methods

Experimental site and soil analysis

A field experiment to evaluate the effect of soil applied zinc and boron on growth, yield and quality of sunflower was conducted during spring 2015-2016 at Agronomic Research Arca, University of Agriculture, Faisalabad, Pakistan. A composite sample at a depth of 30 cm was obtained from different places of experimental area at standard with the help of augar before sowing. Soil sample was analyzed for its physio-chemical properties (Table 1). The percentage of sand, silt and clay was determined by Bouyoucos hydrometer methods. Soil (40 g) was saturated overnight with 1.0% sodium hexameta-phosphate solution and distilled water. Then this was isolated with electric stirrer, transferred to graduated cylinder of one liter. Silt and clay (%) were determined by means of Bouyoucos hydrometer. Textural class was determined by following the international textural Triangle (Moodie et al., 1959). Chemical analysis of the soil was carried out to record the chemical characteristics by following standard procedures (Homer & Pratt, 1961). A clear extract of saturated soil paste was obtained by a vacuum pump. The ECe (dS m^{-1}) was measured by using Jenway. Conductivity meter Model-4070 (Method 21a, 21 c,p. 102).

Table 1
Soil analysis before sowing the crop.

Composition	
Texture	Clay loam
Chemical analysis	
EC	0.58 dsm^{-1}
pH	7.6
Organic Matter	0.86%
Total Nitrogen	0.053 mg kg^{-1}
Available phosphorus	16.8 mg kg^{-1}
Extractable potassium	2.35 mg kg^{-1}
Extractable zinc	0.38 mg kg^{-1}
Extractable boron	0.40 mg kg^{-1}

pH of saturated soil paste (pHs) and Organic matter

Saturated paste of soil (300 g) was prepared by adding distilled water (Method2, p. 84). The saturated paste was allowed to stand as such for overnight and pH was measured by the model HM-12 pH meter. One gram soil was mixed with 10 ml of 1.0 N potassium dichromate solution and 20 ml concentrated sulphuric acid. Then, 50 ml of distilled water and 25 ml of 0.5 N freshly prepared ferrous sulphate solution were added. The excess of ferrous sulphate was neutralized with 0.1 N solution of potassium permanganate to pink end point and at the end percentage of organic matter was determined (Moodie et al., 1959).

Total nitrogen

Ten grams of soil were added in 40 ml of concentrated $E12SO_4$ plus 10 g of digestion mixture (K_2SO_4: $FeSO_4$: $CuSO_4$: 10: 1: 0.5) and then digested the material using the Kjeldhal digestion method. Then 10 ml of the aliquot was taken from this digested material and distillation was carried out with micro Kjeldhal's apparatus. The NH_3 gas evolved was absorbed in a receiver containing 4% boric acid solution and mixed indicator (Bromocresol green and methyl red). After distillation the contents of receiver were titrated against 0.1 N sulphuric acid (Jackson, 1962) and N was calculated by the following formula.

$$\%N = \frac{(V - B)\ \times N \times R \times 14.01 \times 100}{Wt\ \times 1000}$$

Where:

V= Volume of 0.01 N of sulphuric acid used for titration for the sample (ml)

B = Digested blank titration volume (ml)

N= Normality of sulphuric acid solution

R = Ratio between total volume of the digested and sample volume used for distillation

Wt = Weight for air dry soil (g)

Available phosphorus and Extractable potassium

Soil 5 g was extracted with NaHC03 solution and adjusted to pH 8.5. 5 ml of clear filtrate was taken in 100 ml volumetric flask and then 5 ml ascorbic acid was added Volume was made up to the mark. Reading was recorded on spectrophotometer using 880nm wavelength with the help of a standard curve (Watanabe & Olsen, 1965). Extraction was made and the ammonium acetate and extractable K was determined by Corning Flame Photometer-410 after calibrating with K standard solution (Method 58a, p. 132).

Extractable Zinc and Boron

Weigh 10 g air-dry soil (2-mm) into a 125-ml conical flask. Add 20 ml extracting solution. Shake on a reciprocal shaker for 15 minutes at 180 cycles/minute with flasks kept open. Filter the suspensions using Whatman No. 42 filter paper (Method 60a, p. 136).

Zn (ppm)=ppm Zn (from calibration curve)×dilution factor

Weigh 10 g air-dry soil (2-mm) into a polypropylene tube or into a 50-ml

Erlenmeyer flask (Pyrex). Add about 0.2 g activated charcoal (B-free). Add 20 mL 0.05 N of MCl solution. Shake for 5 minutes, and then filter the suspension using a Whatman No. 40 filter paper (Method 56a, p.138).

$$B\ (ppm) = ppm\ B\ (from\ calibration\ curve) \times \frac{V}{Wt}$$

Where:

V = Total volume of the soil extract (ml)

Wt = Weight of air-dry soil (g)

Experimental Design and Layout

The experiment was laid out in randomized complete block design (RCBD) under factorial arrangement with three replications. Net plot size was 4.5m x 6m.

Treatments

Factor (A)

Zinc Fertilizer (Zn) Z_0 = Control, Z_1 = 10 kg ha^{-1}, Z2 = 20 kg ha^{-1}, Z_3 = 30 kg ha^{-1}

Factor (B)

Boron Fertilizer (B) B_0 = Control, B_1 = 1 kg ha^{-1}, B_2 = 2 kg ha^{-1}, B_3 = 3kg ha^{-1}

Seed bed preparation

The seed bed was prepared by giving soil 2-3 ploughing with tractor mounted cultivator to a depth $10^{-1}2$ cm followed by planking, when the soil was reached at proper moisture level.

Sowing of crop

Hybrid sunflower (Hysun-33) was sown on 24th March, 2015. Sunflower hybrid was sown on one side of the ridges by choppa method keeping 75 cm row to row distance using the seed rate of 6 kg ha^{-1}. Plot was irrigated after the sowing. Recommended fertilizer doses of N P K (150-100-60 kg ha^{-1}) was applied to the crop in the form of Urea, DAP (Diammonium Phosphate) and MOP (Murate of potash), respectively. All the phosphorus, potassium and 1/3rd of nitrogen was applied at the time of sowing. Half of the remaining nitrogen was applied with first irrigation and half of it was applied at the time of flowering. Zinc sulphate and borax used as sources of Zn and B, respectively were applied at time of sowing by broadcasting method. All other agronomic practices, except treatments under study were kept uniform for all the treatments.

Irrigation

Generally, spring sowings requires at least four irrigations. The first irrigation was applied 15 days after emergence, second at the completion of the vegetative growth, the third at head formation and the last irrigation was applied at grain filling stage. Irrigation was stopped about one week before harvesting.

Weed Control and earthing up

For the removal of weeds and to maintain the air circulation in the soil, hoeing was done which also increase the water holding capacity. Earthing up was done when crop reached at the height of one foot to provide the support to the plant during wind storms.The first four weeks after emergence are critical because weeds compete with plants at this stage for water, nutrients, space, and light. Manual hoeing was used to destroy the weeds.

Data regarding following parameters was observed by using the standard procedures during study i. e., Days to 50% flowering, days to maturity, number of plants per plot at harvesting, stem diameter (cm), head diameter, number of achenes per head,1000-achene weight (g), biological yield (kg ha^{-1}), plant height at maturity (cm), achene yield (Kg ha^{-1}), harvest index (%), leaf concentration or Zn at heading stage (ppm), leaf concentration or B at heading stage (ppm), achene oil contents (%).

Statistical analysis

The collected data were subjected to statistical evaluation using computer software Statistix 8.1. Treatment means were compared for significant difference by using LSD test at P=0.05 (Steel et al., 1997).

Results and Discussions

Days taken to 50% flowering (days)

Results regarding days to 50% flowering (Table 2) showed non-significant differences among variable levels of Zn and B and interaction of Zn and B levels. Maximum number of days (61.2) was taken when zinc was applied at 10 Kg ha^{-1} whereas minimum numbers of days (61.00) were taken when no zinc was applied for completing 50% flowering. Statistically analyzed data regarding days to 50% flowering showed that number of days to 50% flowering were statistically non-significant at all levels of boron. These findings are matched with Mehmood et al. (2018) who reported that days to 50% flowering were not affected by boron application. These results indicated that zinc and boron application cannot influence the flowering stage. These results are also in line with the findings of Patil et al. (2010). Statistically analyzed data showed that the interactions between zinc and boron levels were also non-significant.

Table 2
Effect of Zinc and Boron application on days taken to 50% flowering of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	60.7^{NS}	60	62.3	61.0	61^{NS}
10	60.3	61.3	60.7	62.3	61.2
20	60.7	61.3	61.3	61.3	61.2
30	61.3	60.7	61.0	60.7	60.9
Mean	60.0^{NS}	60.1	61.1	61.1	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = ^{NS}					

Days taken to maturity

Results regarding days to maturity are presented in (Table 3) Analysis of variance showed that days to maturity were not significantly affected by variable level of zinc and boron. Maximun number of days (81.6) was taken when zinc was applied at 20 kg ha^{-1} minimum number of days (80.3) was taken when zinc was applied at the rate of 30 ha^{-1} for obtaining maturity. These results indicated that different levels of zinc cannot significantly influence the days taken to maturity. These results are confirmed from the findings of Patil et al. (2010). statistically analyzed data regarding days to maturity showed that days taken to maturity were also not significant by applied by different levels of boron. These findings are in line with Mehmood et al. (2018) who reported that days to maturity were not affected by boron application. The interaction was also non-significant. The analysis of variance indicated the interaction between different levels of zinc and boron was also non-significant.

Table 3
Effect of Zinc and Boron application on days taken to maturity of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	80.3^{NS}	79.3	81.6	81.0	80.6^{NS}
10	80.6	81.6	80.3	82.3	81.2
20	81.6	82.0	82.0	81.0	81.6
30	81.6	80.3	79.6	79.3	80.3
Mean	81.1^{NS}	80.8	80.9	80.9	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = ^{NS}					

Number of plants per plot at harvesting

Optimum number of plants per unit area plays an important role to attain higher yields in field crops. Plant population has direct impact in attaining maximum crop yield. Scientists have studied differences on plant growth due to variation in plant density. Results regarding the number of plants per plot at harvesting indicated non-significant changes among variable levels of zinc. (Table 4). Non-significant variances among the variable levels of boron were also observed for number of plants per plot. The interaction between zinc and boron levels was also not significant (Table 3). This might be due to same germination percentage of both the treatments. It can be concluded from these results that zinc and boron application at variable levels have no role on germination of sunflower seed (Patil et al., 2010).

Table 4
Effect of Zinc and Boron application on number of plants per plot at harvesting of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	60.3^{NS}	60	60.3	61	60.4^{NS}
10	59.3	60	61.3	61.3	60.5
20	61.3	61.3	60.3	62.0	61.2
30	61.0	59.3	60	60.3	60.2
Mean	60.5^{NS}	60.2	60.5	61.2	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = ^{NS}					

Plant height at maturity (cm)

Plant height is mainly controlled by its genomic makeup and ecological conditions during the growth period of the crop. The data on plant height at harvesting given in the table 5 showed that plant height was expressively affected by different treatments of zinc and boron. Regarding zinc levels, maximum plant height (147.5 cm) was observed in plots where zinc was applied at the rate of 20 kg ha^{-1} whereas minimum plant height (134.6 cm) was recorded when no zinc was applied which was statistically at par with the Zn @ 10 and 30 kg ha^{-1} application at 20 kg ha^{-1} increased the plant height (10%) over control. These results are in agreement to the findings of Khurana and Chatterjee (2001) who reported that zinc application had substantial effect on plant height sunflower. For interaction (Table 5), analysis variable levels of zinc and boron was found non-significant for plant height hybrid Hysun-33. These results are matched height increased with the combined application of zinc and boron.

Table 5
Effect of Zinc and Boron application on plant height (cm) at maturity of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	127.5^{NS}	137.2	136.1	137.5	134.6 B
10	129.3	131.6	139.2	149.3	137.3 B
20	143.4	146.2	146.9	153.6	147.5 A
30	136.8	140.6	139.0	132.9	137.3 B
Mean	134.2 B	138.9 AB	140.3 AB	143.5 A	
HSD: Zinc level = 2.63, boron level = 2.63, zinc level × boron level = ^{NS}					

Stem diameter (cm)

The data on stem diameter given in table 6 showed that stem diameter was significantly affected by the application of different treatments of zinc and boron. Regarding zinc levels, maximum stem diameter (1.78 cm) was noted in plots where zinc was applied at 20 kg ha^{-1}. Stem diameter was increased by 7.22% with the application of @ 20 kg ha^{-1} over control. Whereas minimum stem diameter (l .66 cm) was recorded in plots where zinc was applied at 30 kg ha^{-1} which was statistically at par with Zn @ 0 and 10 kg ha^{-1}. These results matched with the investigations of Khan et al. (2015) who stated that cell enlargement in growing tissues affected due to the deficiency of boron and it was involved in cell structure hence reduced stem diameter. The interaction between different levels of zinc and boron on stem diameter was also significant. Maximum stem diameter (l .89 cm) was noted in plots where zinc and boron were applied at the rate of 10, 20 and 3 kg ha^{-1}, respectively while minimum stem diameter (1.47 cm) was noted in plots where zinc and boron were applied @ 30 and 0 kg ha^{-1} respectively, Stem diameter was increased 24 % with the combined fertilization of Zn and B @ 30 and 2 kg ha^{-1}, respectively compared to the control. These outcomes are matched with the investigations of Patil et al. (2010), who reported that stem diameter of sunflower increased with the combined application zinc and boron.

Table 6
Effect of Zinc and Boron application on stem diameter (cm) of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	1.53 de	1.55 de	1.73 c	1.86 ab	1.66^{NS}
10	1.59 d	1.61 d	1.59 d	1.89 a	1.67
20	1.57 d	1.78 bc	1.87 ab	1.89a	1.78
30	1.47 e	1.53 de	1.76 c	1.75 c	1.63
Mean	1.54^{NS}	1.62	1.74	1.85	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = 0.094					

Head diameter (cm)

Genetically head diameter is controlled character, but the environment plants are grown which is very important for head diameter growth. For zinc levels, maximum head diameter (17. l cm) was noted in plots where zinc was applied at the rate of 20 kg ha^{-1} which was significantly higher than all other zinc levels (Table 7). However, minimum head diameter (13.3cm) was noted in plots where no zinc and 30 kg ha^{-1} zinc was applied. Head diameter was increased (29%) with Zn fertilization at 20 kg ha^{-1} control. Similar results were obtained by Khurana and Chatterjee (2001), who found that head diameter of sunflower increased by the application of zinc. The boron application at the rate of 3 kg ha^{-1} gave maximum head diameter (15.9 cm). However, minimum head diameter (13.4 cm) was noted in plots where no boron was applied. The outcomes matched with the conclusions of Reddy et al. (2003) and Somroo et al. (2007) who reported that head diameter increased by boron fertilization @ 4.5 kg ha^{-1}. An increase of 19% on head diameter was noted with boron fertilization at 3 kg ha^{-1} over control. They also reported that role of boron is well known in increasing the translocation of photo assimilates from vegetative to reproductive components as it has a dominant role in sugar translocation, having direct impact on metabolic activity which led to increase in head diameter (Reddy et al., 2003). For zinc and boron interaction, significantly maximum head diameter (19.8 cm) was noted in plot where zinc and boron were applied at the rate of 20 and 3 kg ha^{-1}, respectively. However, significantly minimum head diameter (12.37 cm) was noted in plots where no zinc and boron were applied. The head diameter of sunflower was increased (60%) with combined fertilization of Zn at 20 kg ha^{-1} and B at 3 kg ha^{-1} over control. These results coincide with finding of Patil et al. (2010) who stated that head diameter of sunflower increased with the zinc and boron fertilization.

Table 7
Effect of Zinc and Boron application on head diameter (cm) of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	12.37 g	13.23 efg	13.6efg	13.8defg	13.3^{NS}
10	13.53 efg	14.03 def	15.33cd	16.96b	14.9
20	14.7 cde	16.2bc	13.6b	19.83 a	17.1
30	12.8 fg	13.56 efg	13.66 efg	12.96fg	13.3
Mean	13.4^{NS}	14.3	15.1	15.9	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = 1.59					

Number of achenes per head

Number of achenes per head is an important yield related parameter which contribute significantly towards its final yield of sunflower crop. Investigations regarding the number of achenes per head showed significant differences among the different levels of zinc and boron (Table 8). The interaction between zinc and boron regarding number of achenes per head was not significant. For zinc levels, maximum number of achene (993.47) per head was recorded when zinc applied at 20 kg ha^{-1} which was statistically at par with 10 kg ha^{-1} of Zn application. Number of achenes per head was increased (10%) with Zn fertilization at 20 kg ha^{-1} over control. This effect is due to more head size of sunflower hybrid Hysun-33 and it has small size achene and more compact achene in head However, minimum number of achene (862.06) per head was obtained when zinc was applied at 30 kg ha^{-1} which was statistically at par with control treatment. Khurana and Chatterjee (2001) stated that zinc fertilization had enhanced the number of achenes per head. Regarding boron levels, maximum number of achene (988.43) per head were recorded when boron was applied at 3 kg ha^{-1} which was statistically at par with 2 kg ha^{-1} of boron fertilization. Number of achenes per head was increased (12%) with the application of B at 3 kg ha^{-1} over control. The rise in number of achenes may be due to increase in translocation of assimilates from source to sink as 3 and 4 kg ha^{-1} boron application at sowing time (Reddy et al., 2003; Parkash & Mehra, 2006; Somroo et al., 2007). Boron was a vital part in translocation of sugars, which leads to in increased number of achenes per head. The interaction between different levels of zinc and boron was not significant.

Table 8
Effect of Zinc and Boron application on number of achenes per head of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	855.5^{NS}	882.9	918.3	952.2	902.23 Bc
10	889.9	937.2	997.1	1022.9	961.79 AB
20	923.3	962.9	998.8	1088.9	993.47 A
30	881.2	873.9	803.4	889.7	862.06 C
Mean	887.47 B	914. 22 B	929.42 AB	988.43 A	
HSD: Zinc level = 71.77, boron level = 71.77, zinc level × boron level = ^{NS}					

1000-achene weight

Maximum 1000- achene weight 63.53g was noted in plot zin was applied at 20 kg ha-1. Minimum 1000-achene weight (56.88 g) was noted in achene weight is also an important yield component of sunflower which yield potential of sunflower crop (Table 9). These results were in line with the investigations of achene weight Abbas et al. (2010) and M. A. Khan et al. (2009) who reported significant increase a 1000-achene weight with zine fertilization. For boron levels, significantly maximum 1000-achene weight (60.76 g) was noted where boron was applied at 3 kg ha^{-1} which was statistically at par with 1 and 2 kg of boron application. However, minimum 1000-achene weight (57.98 g) was noted where no boron treatment was applied. 1000-achene weight was increased (5%) with the plication of B at 3 kg ha^{-1} over control. These results are matched with the investigations of Oyinlola (2007) and Bilen et al. (2011) who stated that boron applied at the rate of 3 kg ha^{-1} enhanced the 1000-achenes weight of sunflower. The interaction between variable levels of zine and boron was also significant. The minimum 1000-achenes weight (66.73 g) was weighted in the plots where zine and boron applied at 20 and 3 kg ha^{-1}, respectively, 1000-achene weight was increased (15.89 %) with combined application of Zn @ 20 kg ha^{-1} and B @3 kg ha^{-1} compared to control. These results are also confirmed by the investigations of Patil et al. (2010), who concluded that 1000-achene weight of sunflower increased with combined fertilization of zine and boron.

Table 9
Effect of Zinc and Boron application on 1000-achene weight (g) of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	57.58 def	58.13def	58.7 def	59.16 cde	58.39^{NS}
10	58.4def	58.59 def	58.66 def	60.66bcd	59.08
20	60.9bcd	62.67bc	64.05 ab	60.73 a	63.59
30	55.03 f	57.90 bef	58.13def	56.49ef	56.88
Mean	57.98^{NS}	59.33	59.88	60.76	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = 3.93					

Achene yield (kg ha^{-1})

Concerning zinc levels, significantly maximum achene yield (2648.1 kg ha^{-1}) data on achene yield are given in table 10. Ahmed et al (2010), who stated that achene yield of dower was improved with Zn application. Abbas et al. (2010) also observed similar alts with soil application of zinc. For boron levels, significantly maximum achene yield (25524 kg ha^{-1}) was obtained o plots where boron was applied at the rate of 3 kg ha^{-1} which was statistically at par with 1kg ha^{-1} of B application. However, the minimum achene yield (2221.2 kg ha^{-1}) was obtained where no boron was applied. Achene yield was increased (15 %) with the application B at 3 kg ha^{-1} over control. These results matched with the findings of Patil et al. (2010) and Oyinlola (2007), who reported that boron applied at the rate of 3 kg ha enhanced the achene yield of sunflower. The interaction between zine and boron levels was not significant regarding achene yield. The maximum achene yield (2912.3 kg ha^{-1}) was recorded in the plots where zine and boron were applied at the rate of 20 and 3 kg ha^{-1}, respectively.

Table 10
Effect of Zinc and Boron application on achene yield (kg ha^{-1}) of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	2045.7^{NS}	2163.2	2487.1	2333.6	2257.3 C
10	2242.3	2339.5	2467.7	2633.7	2420.7 B
20	2469.3	2569.4	2641.6	2912.3	2648.1 A
30	2127.6	2175	2277.1	2330.1	2227.4 C
Mean	2221.2 B	2311.8 B	2468.4 A	2552.4 A	
HSD: Zinc level = 133.73, boron level = 133.73, zinc level × boron level = ^{NS}					

Biological yield (kg ha^{-1})

Biological yield is the total biomass produced by crop consuming the resources and is an important parameter to regulate the photosynthetic efficacy of a crop. Biological yield showed significant differences at the different levels of Zn and B (Table 11). There was no significant effect of boron on biological yield and interaction between zinc and boron regarding biological yield was also non-significant. Zinc applied at the rate of 20 kg ha^{-1} produced significantly higher biological yield than other zinc levels. However, minimum biological yield (11925.67 kg ha^{-1}) of biological yield was observed with the application of Zn at 20 kg ha^{-1} compared to its control treatment. These results matched with the findings of M. U. Khan et al. (2002) and Abbas et al. (2010) who stated that rise in biological yield might be due to role of zinc in cell division and biomass accumulation. Statistically non-significant results were recorded when boron was applied at the rate of 0, 1, 2 & 3 kg ha^{-1} (using the source boric acid) on biological yield of sunflower Hybrid Hysun-33 per hectare. These results opposed to the findings of Gitte et al. (2005), who reported that biological yield increased with boron fertilization. The interaction between variable treatments of zinc and boron was not significant for biological yield of sunflower hybrid Hysun-33.

Table 11
Effect of Zinc and Boron application on biological yield (kg ha^{-1}) of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	11908.67^{NS}	11916.67	11926.33	11951.00	11925.67 D
10	12238.30	12251.67	12299.67	12342.33	12283.00 C
20	12842.30	12858.00	12931.67	13066.33	12924.58 A
30	12516.00	12489.67	12539.00	12582.67	12531.83 B
Mean	12376.33^{NS}	12379.00	12424.17	12485.58	
HSD: Zinc level = 139.35, boron level = ^{NS}, zinc level × boron level = ^{NS}					

Harvest index (%)

The physiological ability and efficiency of plants for transforming the total dry matter economic yield is called as harvest index. The data on harvest index given in table indicated that harvest index was significantly affected by different levels of zinc and the interaction between zinc and boron regarding harvest index was not significant (Table 12). Regarding zinc levels, the application of 20 kg ha^{-1} remaining at par with Zn level of ha^{-1} gave the maximum harvest index value (20 %). However, significantly harvest index (18 %) was recorded in plots where zinc was applied at the rate of 30 kg ha^{-1}. These results are quite in line with those of Patil et al. (2010), who reported that harvest index percentages were increased by the application of zinc. The boron level of 3 kg ha^{-1} remaining at par with 2 kg ha^{-1} boron level gave the maximum harvest index value (20 %). These results are matched with the findings of Zahoor et al. (2011), who reported that harvest index increased with the application of boron. However, the minimum harvest index (18 %) was obtained where no boron was applied.

The interaction between zinc and boron levels was not significant (Table 12).

Table 12
Effect of Zinc and Boron application on harvest index (%) of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	17.17^{NS}	18.15	20.82	19.53	18.92 B
10	18.32	19.09	20.05	21.34	19.69 AB
20	19.22	19.97	20.42	22.28	20.47 A
30	16.99	17.41	18.15	18.52	17.77 C
Mean	17.93 B	18.66 B	19.86 A	20.42 A	
HSD: Zinc level = 1.05, boron level = 1.05, zinc level × boron level = ^{NS}					

Leaf concentrations or Zn at heading stage (ppm)

The data on leaf Zn concentrations at heading stage (Table 13) showed that Zn concentrations were significantly affected by the application of different levels of Zn and B. Signifacntly maximum Zn concentration (0.672ppm) was found where Zn was applied at kg ha^{-1}. However, significantly minimum Zn concentration (0.3125 ppm) was found no zinc was applied. For boron levels, maximum Zn concentration (0.518 ppm) was found where boron was applied at 3 kg ha^{-1}. However, significantly minimum Zn concentrations (0.475 ppm) Mere found where no boron was applied. The interaction was also significant. Maximum Zn concentration (0.677 ppm) was found where zinc and boron were applied at 30 and 2 kg ha^{-1}, respectively. However, minimum Zn concentrations (0.273 ppm) were found without the applications of B and Zn.

Table 13
Effect of Zinc and Boron application on leaf concentration of Zn at heading stage ppm of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	0.273 g	0.33 f	0.313fg	0.337f	0.3125^{NS}
10	0.42e	0.42 e	0.433 e	0.457e	0.4325
20	0.537 d	0.567d	0.57cd	0.617bc	0.5725
30	0.67 a	0.677 a	0.677a	0.663 ab	0.672
Mean	0.475^{NS}	0.497	0.498	0.518	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = 0.05					

Leaf concentrations of B at heading stage (ppm)

The data on leaf B concentrations at heading stage (Table 14) showed that B concentrations significantly affected by the application of different levels of Zn and B. Maximum B concentrations (0.61 ppm) were found where zinc was applied at 30 kg ha^{-1} However, significantly minimum B concentrations (0.57 ppm) were found where no zinc was applied. The differences between 10 and 20 kg Zn ha^{-1} were not significant. All boron levels differed significantly from one another regarding boron concentration in leaf at heading stage (Table 14). Significantly maximum B concentrations (0.77 ppm) were found where boron was applied at 3 kg ha^{-1}. However, significantly minimum B concentrations (0.41 ppm) were found where no boron was applied. The interaction between Zn and B levels was also significant. B concentration in leaf under variable levels of Zn (0, 10, 20 and 30 kg ha^{-1}) was almost exactly similar in plots where 3 kg of B ha^{-1} was applied and values recorded were also maximum in these plots (0.77ppm). However, minimum B concentrations (0.37 ppm) were found in control treatment without Zn and B application.

Table 14
Effect of Zinc and Boron application on leaf concentration of B at heading stage of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	0.37 g	0.52e	0.63d	0.77ab	0.57^{NS}
10	0.43f	0.52e	0.66cd	0.77a	0.59
20	0.41 fg	0.53 e	0.66cd	0.77a	0.59
30	0.44f	0.56 e	0.71bc	0.76 ab	0.61
Mean	0.41^{NS}	0.53	0.67	0.77	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = 0.05					

Achene oil content (%)

The oil percentage in achene of sunflower reflects its quality. The data regarding oil contents showed that achene oil contents were significantly affected by different of zinc and boron. The interaction between different levels of zinc and boron was not significant (Table 15). Significant maximum oil contents (40 %) were achieved where zinc was applied at the rate of 10 kg ha^{-1}, whereas the remaining Zn levels (0, 20 and 30 kg ha^{-1}) produced statistically similar achene oil contents. An increase in oil contents of 9 % was observed with the application of Zn at 10 kg ha^{-1} over control. The study indicated that B application significantly increased achene oil contents of sunflower. Improved achene oil contents of sunflower hybrids under micronutrients application might be due to enhanced uptake of B in the achenes as B has significant effect on achene oil contents of sunflower (Renukadevi & Savithri, 2003). Ahmed et al. (2010), Sawan et al. (2001) and Sultana et al. (2001) also reported that achene oil contents were increased with the application of zinc fertilizers. The 3 kg B ha^{-1} remaining at par with 2 kg B ha^{-1} gave the maximum oil contents in achene of sunflower. The minimum achene oil contents (37 %) were achieved where boron was applied at the rate of 1 kg ha^{-1} which was statistically at par with control and 2 kg B ha^{-1}. Achene oil contents were increased (3%) with the application of B at 3 kg ha^{-1} compared to control. Our results are in line with Ahmad et al. (2005), who reported that achene oil contents increased with the application of zinc. The statistically analysed data showed that the interactive effects between different levels of zinc and boron were non-significant regarding achene oil percentage of sunflower hybrid Hysun-33.

Table 15
Effect of Zinc and Boron application on achene oil content % of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	36.03^{NS}	36.53	37.03	37.30	36.73b
10	39.17	39.62	40.28	41.40	40.12 a
20	36.70	36.03	37.07	37.17	36.76b
30	36.20	35.57	36.37	37.17	36.33b
Mean	37.03 B	36.94 B	37.69 AB	38.26 A	
HSD: Zinc level = 0.78, boron level = 0.78, zinc level × boron level = ^{NS}					

Achene protein contents (%)

Achene protein contents oil of sunflower also reflects its quality. The data regarding achene protein contents (Table 16) showed that achene protein contents were significantly affected by different levels of zinc and boron and the interaction was also significant. The zinc applied at the rate of 20 kg ha^{-1} gave significantly higher protein contents (20 %) than all other zinc levels. the control and 10 kg Zn ha^{-1} gave statistically similar protein contents. These findings matched with the results of Khurana and Chatterjcc (2001) who described that protein contents were increased with Zn application which might be due to increase in translation, transcription and reduced RNA degradation. Regarding various levels of boron, significantly maximum protein contents (19%) were achieved in the plots where boron was applied at the rate of 2 kg ha^{-1} and it was statistically similar to 3 kg B ha^{-1}. The minimum protein contents (19 %) were achieved from plots where no boron was applied. These results matched with the findings of Oyinlola (2007). The maximum protein contents (22 %) were achieved where zinc and boron were applied at the rate of 20 and 2 kg ha^{-1}, respectively and minimum contents were recorded in control treatment (no zinc and boron). The interaction mainly arose due to non-significant difference among the boron levels where Zn was applied at the rate of 0 and 10 kg ha^{-1} Whereas when Zn was applied at the rate of 20 and 30 kg ha^{-1}, the differences among the boron levels were significant.

Table 16
Effect of Zinc and Boron application on achene protein contents % of sunflower

Zinc level (kg ha^{-1})	Boron level (kg ha^{-1})				Mean
	0	1	2	3	
0	18.23 d	18.4d	18.57d	19.03cd	18.56^{NS}
10	18.73 cd	18.73cd	18.5d	19.2cde	18.79
20	19.07cd	20.43b	21.93a	20.27 b	20.43
30	19.67bc	18.8cd	19.17cd	18.97cd	19.15
Mean	18.93^{NS}	19.09	19.53	19.37	
HSD: Zinc level = ^{NS}, boron level = ^{NS}, zinc level × boron level = 0.97					

Conclusion

It was concluded from this study that higher growth and yield of sunflower can be achieved by application of Zn at 20 kg ha^{-1} and B at 3 kg ha^{-1} under Faisalabad conditions.

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