Research Article

Integrated Use of Boron and Zinc for Enhancing growth, Yield and Quality of Canola

Muhammad Ehsan Safdar[1], Muhammad Asif[1], Amjed Ali[1], Ahsan Aziz[1], Naeem Akhtar[2], Muhammad Shahid Gulrez[1] and Waqas Raza[3*]

[1]Department of Agronomy, College of Agriculture, University of Sargodha, Sargodha 40100, Pakistan; [2]Department of Plant Breeding and Genetics, College of Agriculture, University of Sargodha, Sargodha 40100, Pakistan; [3]Department of Plant Pathology, College of Agriculture, University of Sargodha, Sargodha 40100, Pakistan.

Abstract | To identify the influence of the integrated boron and zinc application on canola's (*Brassica juncea*) growth, quality and yield, a field trial was performed at research farm, Agriculture College, University of Sargodha, Punjab, Pakistan during winter season 2020-21. Treatments comprised of three B (0, 1, and 2 kg ha^{-1}) and three Zn (0, 8, and 10 kg ha^{-1}) levels and their all-possible combinations as their basal application to soil as boric acid and $ZnSO_4$ fertilizers, respectively. RCBD with three blocks was applied. Seed of *AARI Canola* variety was sown in 45 cm apart rows. Maximum CGR (155 g m^{-2}day^{-1}), total dry matter (10663 kg ha^{-1}), LAD (360 days), LAI (4.6), and NAR (34.4 g m^{-2} day^{-1}), plant height (195.0 cm), and silique length (6.06 cm) biological yield (15.67 tons ha^{-1}), seed yield (3.85 t ha^{-1}) and oil yield (1188.3 kg ha^{-1}) of canola were recorded with 2 kg ha^{-1} B + 10 kg ha^{-1} Zn treatment. The enhancement in seed and oil yield of canola seems to be due to improvement in seeds per silique (29) and 1000-seed weight (4.25 g). A synergistic relationship might exist between these two nutrients as their combined application showed greater effect in enhancing growth and yield of canola over sole application. Further, both nutrients enhanced the uptake of each other. We concluded that the application of 10 kg ha^{-1} zinc combined with 2 kg ha^{-1} boron can maximize the canola yield, net benefit (Rs. 706765) and benefit cost ratio (3.47), and therefore recommend this a feasible production technology for canola.

Received | December 07, 2022; **Accepted** | February 14, 2023; **Published** | March 28, 2023
***Correspondence** | Waqas Raza, Department of Plant Pathology, College of Agriculture, University of Sargodha, Sargodha 40100, Pakistan; **Email:** waqasraza61@yahoo.com
Citation | Safdar, M.E., M. Asif, A. Ali, A. Aziz, N. Akhtar, M.S. Gulrez and W. Raza. 2023. Integrated use of boron and zinc for enhancing growth, yield and quality of canola. *Sarhad Journal of Agriculture,* 39(1): 287-297.
DOI | https://dx.doi.org/10.17582/journal.sja/2023/39.1.287..297
Keywords | AARI canola, Boron, *Brassica juncea*, Fertilizers, Oil yield, Seed yield, Zinc

Introduction

Pakistan is facing shortage of edible oil as gap between its demand and yield is increasing day by day. Local production and demand of edible oil are 0.374 and 3.291 million tones, respectively. The gap of 2.917 m. tones of edible oil is bridged up by import that is of value US$ 3.419 billion. Increase in edible oil is vital to meet domestic demand and industrial products while also conserving foreign currency, and it has the potential to become a major source of employment in the coming years (GoP, 2020-21). Oilseed crops play a critical part in providing vegetable oil that contains important fatty acids as well as vitamins A, K, D and E which are necessary for the body's function (Kostik *et al*., 2013). Besides other oilseed crops, canola may be an important oilseed crop to improve local production of oil in the country. At global level, it contributes almost 15 percent to total vegetable oil and is ranked at third position after soybean and palm (Banga *et al*., 2007). In Pakistan, its share is around 10% in vegetable oil production (GoP, 2020-21). Mustard and rape contain erucic acid as their typical constituent that is undesirable as edible oil (Wendlinger *et al*., 2014). Despite presence of erucic acid, mustard oil in food provides many health benefits (Poddar *et al*., 2022). Low level erucic acid and glucosinolate varieties of rapeseed and mustard have been evolved are called canola varieties or hybrids (Barthet, 2016). *AARI Canola* (*Brassica juncea* L.) is the canola variety of mustard and farmers prefer due to short duration, tolerance to shattering and omega-3 oil contents. It is a member of family *Cruciferae* and it is a main oilseed crop of the sub-continent. It contains oil (40-46%) and protein (38-40%). It is also used as green leafy vegetable. *Brassica juncea*is more adaptable oilseed crop than *B. napus* in arid areas (Mahmood *et al*., 2017). *B. juncea* seeds having think outer wall, high oil and protein contents and siliques are shattering tolerance (Akmal *et al*., 2011).

Although primary macronutrients (N, P and K) are of utmost importance in crop growth, yet exploring maximum yield potential of cultivars is impossible without micronutrients (Nataraja *et al*., 2010). Among eight micronutrients (Fe, Zn, Mn, Mo, Cu, B, Cl and Ni) (Ross and Shuman, 1995), zinc and boron are ranked first and second most deficient elements in almost all the soils throughout the world including Pakistan (Alloway, 2008; Imtiaz *et al*., 2010). The Zn deficiency mostly prevails in cereals while boron has been found to be deficient primarily in dicotyledonous crops (Alloway, 2008). Deficiency of micronutrients disturbs plant yield but also quality and results in despaired human and animal health (Malakouti, 2007). A thorough study on role of micronutrient on crop yield and quality has been done since last decade (Malakouti and Tehrani, 2005). Substantial enhancements in yields of different crops have been reported. For instance, Zn application at farmers' field resulted in an increased yield of sugarcane, rice, wheat, maize sunflower and potato within the range of 8 to 22% whereas B application in different crops within the range of 7 to 21% (Rashid *et al*., 2006). According to FAO (2014), almost two billion people on this earth are being affected by micronutrient deficiencies due to less intake and assimilation of minerals and vitamins. This is strongly linked with the low micronutrient contents in food (Welch and Graham, 2004). Thus increase in micronutrient content of crops through improved micronutrient application i.e. agronomic bio-fortification would be a potential approach in this regard (Rehman *et al*., 2018). Bio-fortification of oilseed crops through soil application of B and Zn would not only be helpful in increasing the yields of these crops, but can also act a useful strategy to solve the problem of micronutrient deficient food intake in developing countries (Ngozi, 2013). Due to intensive cropping, high soil pH and calcareous soils, B and Zn are most widespread deficient micronutrients in croplands of Pakistan, that lead to lower crop yield and quality of produce (Rehman *et al*., 2018; Rehman *et al*., 2022). Zn in combination with B, increases Zn concentration in plants which induces more flowering and minimizes fruit fall (Mousavi *et al*., 2007).

Boric acid is an available form of boron (B) in soil. B is immobile micronutrient and thus needed continuously to plants at all growth stages (Brown and Shelp, 1997). Globally among micronutrients, Deficiency of B is the dominant problem after Zinc (Shukla *et al*., 2014). Most of the areas across Pakistan face 50-60% B deficiency due to calcareous soils (Rashid *et al*., 2002). It has vital role in cell division, carbohydrates regulation and protein metabolism, and these contribute reproductive stage and seed formation (Tanaka and Fujiwar, 2008). Its deficiency at flowering stage, resulted in deformation of pollen tube and inhibits fertilization which caused empty seed (Pandey and Gupta, 2013). Boron use efficiency can be improved by several strategies for example addition in soil, foliar application or band placement in soil (Farooq *et al*., 2018). However, accurate and enough concentration of B is required throughout the whole growing season for the crop development, quality and yield (Degryse, 2017).

Zinc (Zn) is a vital micronutrient plays key role in growth, development and defense (Broadley *et al*., 2007). It is a compulsory element for plant growth, activator of carbonic anhydrase and aldolase thus regulate enzymatic reactions, essential for carbohydrate metabolism, cellular membranes stability, oxidation reactions, protein synthesis, chlorophyll biosynthesis and for regulation of growth (Mousavi *et al*., 2013). Plants having Zn deficiency are more pronounce to diseases (Gupta *et al*., 2012).

Previous studies have shown that B and Zn are inevitable elements in the production of oilseeds canola by sustaining the productivity of canola. This may be attributed to improvement in growth, yield attributes like branching, silique number and seed weight and oil content of *B. juncae* by B and Zn application (Yadav *et al*., 2016; Afsahi *et al.* 2020). To bridge-up the existing yield gap between average and potential yields of rapeseeds in the country, role of micronutrients could not be ignored. Although researchers have proved the role of B and Zn alone or in combination in enhancing yields of various crops, little information is available regarding influence of soil applied B and Zn with one another alone and in combination on canola growth and yield under subtropical semiarid area of Punjab having calcareous soils. Therefore, it was hypothesized that combined B and Zn effect on growth, yield and quality of canola is higher than their individual effects, so a study was planned to know the best interaction of B and Zn levels for canola under agro-ecological conditions of Sargodha.

Materials and Methods

Experimental site description

The field trial was laid out in the University of Sargodha's Agronomic Farm Area in Pakistan during winter season 2020-21. Climate is subtropical semiarid type where mean annual precipitation is 400±5 mm. Weather data of the growing period (November-April) 2020-21 have been presented in Figure 1. Data indicated that minimum monthly average temperature (14.3°C) in the month of January whereas maximum (39.2°C) in the month of April. Soil physicochemical analysis of trial was carried out and soil data has been presented in Table 1. The soil of experimental site related to the Bhalwal soil series (aridisol-clay loam, Haplic Yermosols according to FAO classification) containing 0.65% organic matter and 0.37% nitrogen.

Table 1: *Physio-chemical analysis of soil from experimental area (University of Sargodha's College of Agriculture, Sargodha, Pakistan).*

Characteristics	Soil sample depth		
	30 cm	**60 cm**	**Mean**
Soil pH	7.7	8.0	7.85
Organic matter (%)	0.70	0.60	0.65
N (%)	0.44	0.31	0.37
Available P (ppm)	6.8	9.6	8.2
Ex-tractable K (ppm)	145	130	137.5
Texture class	Clay loam	Clay loam	-

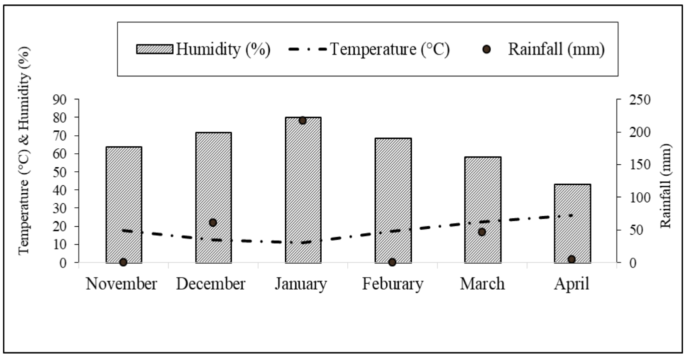


Figure 1: *Meteorological data of the crop growing season (Winter 2020-21).*

Experimental details and crop husbandry

Before conducting experiment, firstly field was irrigated and when soil reached to proper *water* condition, then two ploughings with moldboard plough, two cultivations with narrow tine cultivator followed by two planking's for root and seed bed preparation were carried out. Canola (*Brassica juncea* L.) (cv. *AARI Canola*) seed was taken from Ayub Agriculture Research Institute, Faisalabad, Pakistan, treated with fungicide (thiophenatemethyl) @ 2.5 g per kg seed and were sown on flat leveled field by using manually operated one-tinned hand drill at depth of 2 cm using 5 kg seed ha^{-1}. Spacing between crop rows and plants within a row was kept 0.45 m and 0.1 m, respectively. Sowing was done on 29th of October, 2020. Manual thinning was accomplished 3 weeks after sowing at 4 true leaf stages to maintain plant population. Experimental treatments were; B 0 + Zn 0 (kg ha^{-1}), B 0 + Zn 8 (kg ha^{-1}), B 0 + Zn 10 (kg ha^{-1}), B 1 + Zn 0 (kg ha^{-1}), B 1 + Zn 8 (kg ha^{-1}), B 1 + Zn 10 (kg ha^{-1}), B 2 + Zn 0 (kg ha^{-1}), B 2 + Zn 8 (kg ha^{-1}) and B 2 + Zn 10 (kg ha^{-1}). Net size of plot was 4 m × 2.25 m and RCBD was used and replicated thrice. After 30 days of sowing, field was firstly irrigated while subsequent irrigations were applied at flowering, silique formation and seed formation.

In the treatment's plots, 70% of the plant available soil moisture content was sustained throughout crop growing period by monitoring it with the help of Tensiometer (Model RM 627). A total of 4 irrigations (16 acre inches) each of 3 acre inchest rough surface border irrigation method were applied throughout growing season. Zinc sulphate granular (33% Zn) and boric acid (17.5% B) for Zn and Brespectively were applied at sowing time according to the treatment plan. Nitrogen (N), potash (K) and phosphorus (P) were applied at 23, 12 and 23 kg ha^{-1} as urea, sulfate of potash and diammonium phosphate, respectively. Full dose of K and P along with 1/3rd N were applied at sowing of crop. While remaining N was applied in three equal splits at flowering, silique and seed formation growth stages. Weeding was done twice to control weeds. Two manual weedings were done during at 2nd and 5th week after sowing before canopy closure. All the obligatory cultural, other management practices were uniformly done based on the crop requirements in all the plots. When canola plants reached their maturity, their siliques were detached manually from the plants and then threshed in on 15th April, 2021.

Data collection

Data of plant growth, yield and yield contributing components, B and Zn contents in leaves and oil content in seed of canola were recorded as described below:

Growth of canola

For leaf area index, leaf area duration, crop growth rate and total dry matter, 10 plants at random were harvested out of each plot 30 days after sowing with interval of 10 days up to 90 DAS. Those were dried in an electric oven and then weighed by an electric balance and then total dry matter in kg per ha was estimated from it. Leaf area at different harvests was measured with leaf area meter (LI-3000C).Leaf area index (LAI) was determined as the ratio of leaf area to ground area as recommended by Watson (1952) by following formula:

$$LAI = \frac{Leaf\ area}{Land\ area}$$

Rate of crop growth was computed according to method recommended by Watson (1952):

$$\text{CGR} = \text{W2} - \text{W1}/\ (\text{T2} - \text{T1})$$

Where; W_1 plant dry weights at periods T_1 and W_2 plant dry weights at periods T_2. Average crop growth rate was computed via combining all CGRs computed at all harvests. Leaf area duration (LAD) was determined by the following formula suggested by Hunt (1978).

$$\text{LAD} = (\text{LAI1} + \text{LAI2})/2 \times (\text{T2} - \text{T1})$$

Where; LAI_1 and LAI_2 were the leaf area at time T_1 and T_2, respectively. Cumulative LAD was determined at final harvest by sum up all LAD values at different stages.

The NAR (average net assimilation rate) was computed by utilizing following equation of Hunt (1978).

$$NAR = \frac{TDM}{LAD}$$

Where, TDM and LAD represent the total dry matter and leaf area duration at last harvest correspondingly, at last harvest (90 DAS).

Ten randomly selected mature canola plants per plot were measured for their height with the help of meter rod. By picking five pods from two plants in each pot, the pod length was computed. After manually removing each pod, pod length was measured using a scale, and the average was calculated. At maturity, one square meter area from each plot was selected randomly and harvested, dried in oven till constant weight and then weighed. Biological yield in tons per hectare was then calculated from it.

Yield and yield related traits

At physiological maturity, yield related characters such as siliques per plant, seeds per silique, and 1000 seed weight of canola were measured. For this purpose, siliques were manually detached from plants then threshed manually for seeds per silique. Weight of thousand oven-dried (at 70°C for 24 h) seeds was recorded with the help of an analytical balance (Model Number: HC2204). Seed yield of whole plot was recorded by harvesting and threshing canola plants through weight balance (PL 3200+ L Japan) in kg and then converted into t/ha.

Boron and zinc contents in leaves

To determine the Boron and Zinc contents of mature canola plants, leaves were excised, cleaned and dried in oven at 65°C for 48 hours. An electric grinder was used to grind the leaves. B was determined by transforming the material into ash in a muffle furnace at 550°C for six hours. Material was treated with 0.36 N H_2SO_4. The azomethine-H method was applied to determine the B content using a spectrophotometer at 420 nm (Bingham, 1982). For Zinc content, 0.5 g leaf powder was digested in HNO_3 and $HClO_4$ with 2:1 ratio for 6 h (Allen *et al*., 1986). The volume of mixture was made 25 ml by adding distilled water. Zinc contents in the sample was determined by using atomic absorption (AA-6300, Shimadzu, Japan).

Estimation of oil yield

Oven dried canola seeds were crushed through electric grinder. Three samples per treatment each of 3.5 g seed powder were used for oil extraction. De-fattening of samples was carried out in a Soxhlet's apparatus at 60°C for 8 h. Each sample took 180 g of petroleum ether solution. Oil-free seed samples baked at 50°C for 24 hours. The oil yield was determined by multiplying seed yield with oil content.

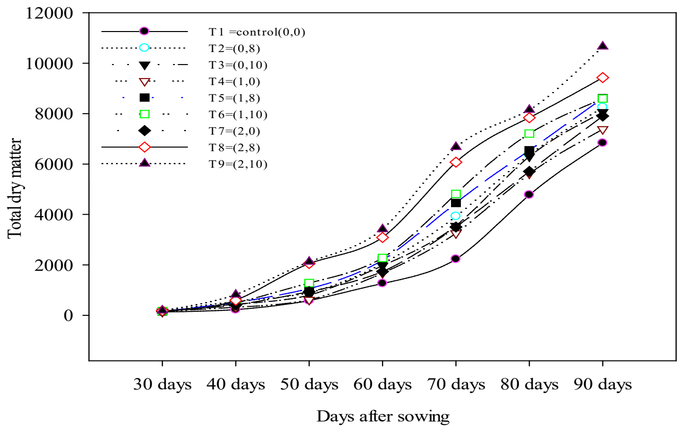
Statistical and economic analysis

Data of all parameters were subjected to Fisher's analysis of variance technique and data means were separated with Tukey's honestly significance test (HSD) at 5% probability level (Steel *et al*., 1997). Statistix 8.1 software was used for analyzing data. The graphs were prepared using Sigma Plot software (Sigma Plot (r)- Scientific, 2008). The economic analysis of treatments was determined on the basis of market prices of boric acid, zinc sulfate fertilizers and canola seed by the procedure as described by CIMMYT (1988). The net benefit was calculated by deducting gross income from variable cost, and benefit-cost ratio as ratio of benefit over control and variable cost.

Results and Discussion

Growth of canola

The presentation of data related to growth of canola has been given in Figures 2 and 3 and Table 2. Total dry matter and leaf area duration showed a gradual increase with increase in crop growth duration from 30 to 90 days after sowing. However, the steepest rise in total dry matter and leaf area duration reaching their maximum values (10663 kg haper ha and 360 days, respectively) at 90 DAS was seen in response to the highest boron (2 kg per ha) and zinc (10 kg per ha) levels.



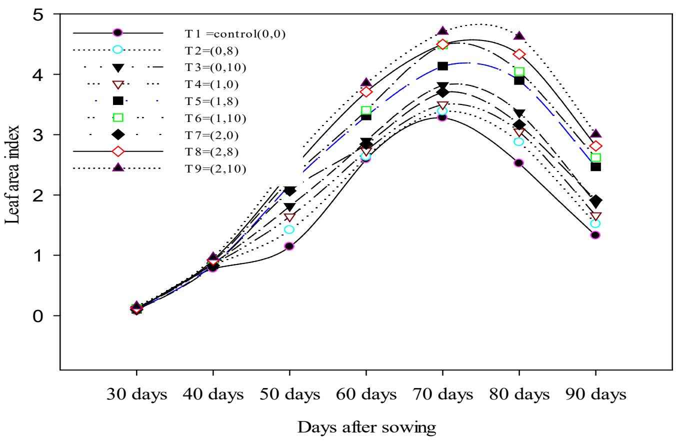


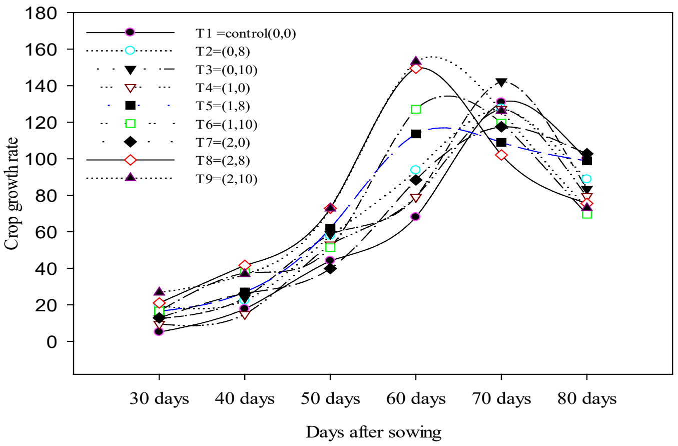
Figure 2: *Total dry matter (kg ha^{-1}) and leaf area index of canola under the influence of different boron and zinc nutrient combination.*

Table 2: *Role of soil applied boron and zinc on net assimilation rate, plant height, silique length and biological yield of Canola under field condition.*

Treatment (B, Zn kg ha^{-1})	Net assimilation rate (g m^{-2} d^{-1})	Plant height (cm)	Silique length (cm)	Biological yield (t ha^{-1})
T1(Control)= 0, 0	26.1 b	161.70 h	3.07 f	10.68 d
T2 = 0, 8	27.2 ab	174.60 f	3.44 ef	11.41 d
T3= 0, 10	27.5 ab	177.83 e	3.70 de	11.59 d
T4 = 1, 0	29.1 ab	171.77 g	3.34 ef	13.05 c
T5= 1, 8	29.2 ab	183.27 d	4.00 cd	13.66 bc
T6= 1, 10	29.8 ab	185.80 c	4.50 bc	13.89 bc
T7= 2, 0	29.0 ab	179.40 e	4.03 cd	14.06 bc
T8= 2, 8	30.9 a	190.87 b	5.00 b	14.72 ab
T9= 2, 10	34.4 a	195.05 a	6.06 a	15.67 a
HSD (5%)	7.6819	1.6109	0.5172	1.4353

According to the honestly significant difference test ($P \leq 0.05$), the letters in the column represented significant differences between treatments.

LAI and crop growth rate of canola crop followed an ascending trend at initial phases of crop and then declined near maturity. At peak growth phase of canola, the higher B (2 kg per ha) and Zn (10 kg per ha) combination resulted in the higher values of LAI (4.6) and CGR (155 g m^{-2} day^{-1}) (Figures 2 and 3). Similar was the case with other growth parameters of canola where same treatment (B 2 and Zn 10 kg per ha) caused significantly highest values of NAR (34.4 g m^{-2} day^{-1}), plant height (195.0 cm), silique length (6.06 cm) and biological yield (15.67 t ha^{-1}) of canola over all other treatments (Table 2). The probable reasoning of enhanced growth and underlying growth indices due to B and Zn application seems to be due to higher rate of cell division, photosynthesis and metabolism as these nutrients are involved in activation of photosynthetic enzymes and growth hormones as well as translocation and metabolism of sugars (Tanaka and Fujiwar, 2008; Mousavi *et al*., 2013). The highest dry matter production by mustard cultivars as a result of boron application was also observed by Choudhary and Bhogal (2013). Sahito *et al*. (2014) demonstrated the greatest vegetative growth of mustard in response to highest (10 kg ha-1) application rate of zinc. However, significant enhancement in growth attributes of *Brassica juncea* by the integrated application of B and Zn was observed by the Kour *et al*. (2017) and Mehera (2022).



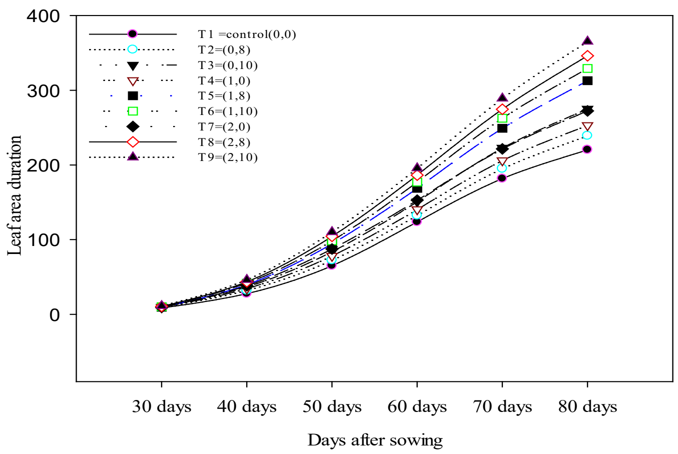


Figure 3: *Cop growth rate (g m^{-2} d^{-1}) and Leaf area duration (days) of canola under the influence of different boron and zinc nutrient combinations.*

Seed and oil yield and yield related traits of canola

Data pertaining to seed yield and yield contributing traits of canola have been given in Table 3. The results showed that in comparison to control, all B and Zn combinations enhanced these parameters. However, B at 2 kg per ha+ Zn at 10kg perhaattained significantly (P≤0.05) the highest improvement (34%) in siliques per plant and seeds per silique (61%) than those observed with all other treatments (Table 3). The same treatment also yielded significantly the higher (50% than control) 1000-seed mass (Table 3). Resultantly, the seed yield of plots fertilized with B at 2 kg per ha+ Zn at 10kg per ha was also statistically higher up to132% than control (Table 3). Similarly, significantly the maximum oil and canola yield (1188 kg ha^{-1}) was recorded with combined B at 2 kg per ha with 10 kg ha^{-1} Zn. Regarding the uptake of these nutrients, B contents (17.46 mg kg^{-1}) in leaves of canola fertilized with 2 $kgha^{-1}$ B in combination with 10 kg ha^{-1}Zn was significantly higher (up to 15%) than those fertilized with Bsole application at the same rate i.e., 2 kg per ha (Table 4). Similarly, the leaves Zn content (39.42 mg per kg) of canola plants fertilized with 10 kg per ha Zn combined with 2 kg per ha B was significantly higher (up to 17.5%) than those solely fertilized with same level of Zn (Table 4). The increase in B and Zn contents of canola leaves in response to combined application of these nutrients as compared to their individual application indicated the existence of synergistic relationship between them regarding their uptake.

Table 3: *Role of soil applied boron and zinc on seed yield and yield components of Canola under field condition.*

Treatment (B, Zn kg ha^{-1})	Silique number per plant	Number of seeds $silique^{-1}$	1000-seed weight (g)	Seed yield (t ha^{-1})
T1(Control)	200 e	18.66 g	2.82 d	1.66 e
T2 = (0,8)	204 e	21.33 f	3.20 cd	2.83 cd
T3= (0,10)	237 cd	22.00 ef	3.35 c	2.97 c
T4 = (1,0)	249 bc	22.66 def	3.15 cd	2.58 d
T5= (1,8)	230 d	23.66 cde	3.48 bc	3.40 b
T6= (1, 10)	232 cd	24.33 cd	3.87 ab	3.64 ab
T7= (2,0)	229 d	25.00 bc	3.15 cd	3.01 c
T8= (2, 8)	260 ab	26.33 b	3.86 ab	3.50 b
T9= (2, 10)	268 a	29.00 a	4.25 a	3.85 a
HSD(P≤0.05)	17.20	1.7801	0.4339	0.2984

According to the honestly significant difference test (P ≤ 0.05), the letters in the column represented significant differences between treatments.

Table 4: *Role of soil applied boron and zinc on oil yield, B content in leaves and Zn content in leaves of canola under field condition.*

Treatment (B, Zn kg ha^{-1})	Oil yield (kg ha^{-1})	B content in leaves (mg kg^{-1})	Zn content in leaves (mg kg^{-1})
T1(Control)	540.3 e	10.25 g	27.46 i
T2 = (0,8)	669.3 d	11.13 f	32.13 f
T3= (0,10)	761.7 c	11.37 e	33.53 e
T4 = (1,0)	666.0 c	14.12 d	29.66 h
T5= (1,8)	722.5 c	14.24 d	34.18 d
T6= (1, 10)	773.7 c	14.57 c	35.58 c
T7= (2,0)	573.7 c	15.19 b	30.13 g
T8= (2, 8)	1097.8 b	15.22 b	37.46 b
T9= (2, 10)	1188.3 a	17.46 a	39.42 a
HSD (P≤0.05)	17.34	0.13	0.11

According to the honestly significant difference test(P ≤ 0.05), the letters in the column represented significant differences between treatments.

Table 5: *Effect of different combinations of zinc and boron on economic returns from canola during year 2020 at UOS.*

Treatment (B, Zn kg ha^{-1})	Gross income (Rs. ha^{-1}) (Seed + Stalk)	Total variable Cost (Rs. ha^{-1})	Net benefits (Rs. ha^{-1})	Benefit over control	Benefit cost ratio
T1(Control)	353600	-	353600	-	-
T2 = (0,8)	599300	98050	501250	147650	1.51
T3= (0,10)	628700	98850	529850	176250	1.78
T4 = (1,0)	546800	96238	450562	96962	1.01
T5= (1,8)	719000	99488	619512	265912	2.67
T6= (1, 10)	769600	100298	669302	315702	3.15
T7= (2,0)	637100	97675	539425	185825	1.90
T8= (2, 8)	740000	100925	639075	285475	2.83
T9= (2, 10)	808500	101735	706765	353165	3.47

Price of Canola = Rs.210 /Kg, Price of boric acid = Rs.250/Kg, Price of Zinc Sulfate = Rs.134/kg.

Improvement in yield and yield attributes of canola with B+Zn application might be possible due to increased rate of assimilates' synthesis, their mobility to potential sinks and efficient pollination and seed development. Further, combined B and Zn application was proved to be more beneficial than their individual application with respect to increased growth and yield of canola. It shows that there may be some synergistic relationship exists between B and Zn nutrient. Our findings corroborate the results of Shoja *et al.* (2018) who noted significantly higher seed yield, 1000 seed weight, seeds per silique, seed oil content and leaf B and Zn content of rapeseed by integrated application of B and Zn over sole application. The synergistic effect of B and Zn on yield and underlying plant traits have also been verified by other researchers. Kanwal *et al.* (2009) observed substantial and consistent increase in yield and yield contributing traits of maize plants by appropriate B and Zn application to the crop root zone. Similarly, Aref (2010) demonstrated that combined effect existed between both micronutrients that improved plant height and seed yield and yield traits of crops with lower concentration of B and Zn in soil profile. This may be sufficient uptake of B by plants in B poor soils, therefore B application in combination with Zn boosted-up plant growth (Shaaban *et al.*, 2004). Furthermore, B application in soil speed up the rate of photosynthetic rate and chlorophyll contents that finally increased the dry matter that leading to increased growth and production (Rehman *et al.*, 2022; Tariq *et al.*, 2014). Moreover, soil applied B showed higher leaf area of *Brassica napus* which may be due to increased indole acetic acid hormone production through B application which favors plant growth and development (Zhou *et al.*, 2016). An appropriate dose of B and Zn helped the plants to improve growth and yield traits (Hall, 2008). Appropriate dose of B to sunflower before sowing enhanced the transfer of photo-assimilates from roots to other sections of the plant, as well as in the development of pollen tube elongation, which leads to a rise in achene number (Silva *et al.*, 2011). Numerous studies showed that sole B and Zn application improved the growth as well as yield of different crops including sunflower, maize, cotton, chickpea, rapeseeds and canola (Morshedi and Naghibi, 2004; Fontes *et al.*, 2008; Rehman *et al.*, 2019; Potarzycki and Grzebisz, 2009; Rehman *et al.*, 2022). The improvement in plant uptake and positive impact of B and Zn in different crops due to existence of synergistic relation between B and Zn has been noted by different studies (Yang *et al.*, 2009; Shaaban *et al.*, 2004; Kour *et al.*, 2017; Shoja *et al.*, 2018; Kumar *et al.*, 2019; Mehera, 2022).

Deficiency of B inhibited the growth of petiole and peduncle cells and reduced growth and seed yield (de Oliveira *et al.*, 2006). Additionally, shorter height of canola at other B + Zn doses may be slight difference between insufficiency and excess, which may disturb the plant parts and restrict plant development and seed yield and yield traits without any visible symptoms (Satya *et al.*, 2009). Moreover, decrease in growth and seed yield in absence (control) or low/higher dose of B was due to decrease in enzymatic reactions that control cell division and elongation, while their excessive levels also resulted in imbalance of different enzymes resulting in reduction of plants height, seed yield and yield traits (Silva *et al*., 2011).

The significant improvement in oil yield of canola in response to higher dose of B occurred might be due to involvement of Bin the production of higher fatty acids compounds (Kalantar and Dezfouli, 2019).

Economic analysis

Table 5 shows a comparison of net benefit and benefit-cost ratios for various Zn and B treatments in 2020. Among all Zn and B combinations, the greatest net benefit (Rs. 706765) and benefit cost ratio (3.47) were got from treatment applied with B 2 kg per ha + Zn 10 kg per ha. Treatment receiving B 1 kg per ha+ Zn 10 kg per ha was proved to be second. This treatment is followed by the treatment where B and Zn were applied at 1 and 10 kg per ha, accordingly as it got the second highest values of net benefit (Rs. 669302) and benefit-cost ratio (3.15).

Conclusions and Recommendations

It is concluded that 2 kg per ha boron + 10 kg per ha zinc is the best combination of these micro-nutrients as it gave the highest yield and economic benefit of canola. Therefore, it is recommended to growers that basal application of these two nutrients should be made to enhance the canola yield and profit under agro-ecological conditions of Sargodha Punjab, Pakistan.

Acknowledgements

The authors acknowledge the Department of Agronomy, College of Agriculture, University of Sargodha, for funding to conduct this study.

Novelty Statement

Demand and importance of oilseed crops in Pakistan is increasing day by day, Pakistan expends US$ 3.68 billion to import edible oil. We can improve yield and quality of canola and hence oil production through B and Zn application and can reduce oil import bill.

Author's Contribution

Muhammad Ehsan Safdar: Conceived the idea, facilitated and supervised the experiment.
Muhammad Asif: Guided for layout, field experimentation and writing of manuscript.
Amjed Ali: Helped in data collection
Ahsan Aziz: Helped in manuscript write-up.
Naeem Akhtar: Guided and helped for data analysis.
Muhammad Shahid Gulrez: Executed the field Trial and participated in manuscript writing.
Waqas Raza: Guided and helped for data analysis and manuscript correspondence.

Conflict of interest

The authors have declared no conflict of interest.

References

Afsahi, K., M. Nazari, H. Omidi, F. Shekari and A.A. Bostani. 2020. The effects of different methods of zinc application on canola seed yield and oil content. J. Plant Nutr., 43(8): 1070-1079. https://doi.org/10.1080/01904167.2020.1724299

Akmal, M., T. Nafis, K.J. Mirza, P. Alam, A. Mohammad, A. Mujib and M.Z. Abdin. 2011. High frequency somatic embryogenesis in mustard crop (*Brassica juncea* L. cv. Pusa jai kisan): Microscopic and histological analyses. Aust. J. Crop Sci., 5(13): 1783-1789.

Allen, S.E., H.M. Grimshaw and A.P. Rowland. 1986. Chemical analysis. Methods in plant ecology. Back well scientific publications.

Alloway, B.J., 2008. Zinc in soils and crop nutrition. S. edition (Ed.). 135. Brussels, Belgium and Paris, France: IZA and IFA.

Aref, F., 2010. Influence of zinc and boron interaction on residual available iron and manganese in the soil after corn harvest. Am. Eurasian J. Agric. Environ. Sci., 8(6): 767-772.

Banga, R.S., S. Bisht and A. Yadav. 2007. Proceedings of the 12th international rapeseed congress, 26-30 March, sustainable development in cruciferous oilseed crops production. Wuhan, China 3: 246-247.

Barthet, V.J., 2016. Canola: Overview. Ed. Colin Wrigley, Harold Corke, Koushik Seetharaman, Jon Faubion. Encycl. Food Grains (Second Eds.), Acad. Press, pp. 237-241. https://doi.org/10.1016/B978-0-12-394437-5.00029-2

Bingham, F.T., 1982. Boron. In: Page A.L. (ed.): Methods of Soil Analysis. Madison, Am. Soc.

Agron., pp. 431–447. https://doi.org/10.2134/agronmonogr9.2.2ed.c25

Broadley, M.R., P.J. White, J.P. Hammond, I. Zelko and A. Lux. 2007. Zinc in plants. New Phytol., 173(4): 677-702. https://doi.org/10.1111/j.1469-8137.2007.01996.x

Brown, P.H., and B.J. Shelp. 1997. Boron mobility in plants. Plant Soil., 193(1): 85-101. https://doi.org/10.1023/A:1004211925160

Choudhary, S.E.E.M.A. and N.S. Bhogal. 2013. Response of mustard cultivars to boron application. Ann. Plant Soil Res., 15(2): 131-133.

CIMMYT, 1988. From agronomic data to farmer recommendations: An economic training manual. Completely revised edition. Mexico. D.F.

de Oliveira, R.A., C.R.D. Milanez, M.A. Mores-Dllaque and C.A. Rosolem. 2006. Boron deficiency inhibits petiole and peduncle cell development and reduces growth. J. Plant Nutr., 29: 2035–2048. https://doi.org/10.1080/01904160600932617

Degryse, F., 2017. Boron fertilizers: Use, challenges and the benefit of slow release sources. A review. J. Boron, 2(3): 111-122.

FAO, 2014. Building a common vision for sustainable food and agriculture. Principles and Approaches. Food and Agriculture Organization of the United Nations (FAO). Rome. https ://www.fao.org/3/a-i3940e.pdf. Accessed 5 Dec 2015 (2014).

Farooq, M., A. Rashid, F. Nadeem, S. Stuerz, F. Asch, R.W. Bell and K.H. Siddique. 2018. Boron nutrition of rice in different production systems. A review. Agron. Sustain. Dev., 38(3): 1-24. https://doi.org/10.1007/s13593-018-0504-8

Fontes, R.L., J.F. Medeiros, J.C. Neves, O.S. Carvalho and J.C. Medeiros. 2008. Growth of Brazilian cotton cultivars in response to soil applied boron. J. Plant Nutr., 31(5): 902-918. https://doi.org/10.1080/01904160802043247

Government of Pakistan (2020-21). Economic survey of Pakistan. Finance Division Economic Advisor's. Islamabad, pp. 121.

Gupta, S.K., A.K. Rai, S.S. Kanwar and T.R. Sharma. 2012. Comparative analysis of zinc finger proteins involved in plant disease resistance. https://doi.org/10.1371/journal.pone.0042578

Hall, D., 2008. Boron fact sheet. http://www.soilquality.org.au/factsheets/boron (Retrieved on 13th October, 2012 at 14:45pm) 2008.

Hunt, R., 1978. Plant growth analysis. Edward Arnlod (Pub.) Ltd., 96: 8-38.

Imtiaz, M., A. Rashid, P. Khan, M.Y. Memon and M. Aslam. 2010. The role of micronutrients in crop production and human health. Pak. J. Bot., 42(4): 2565-2578.

Kalantar, A.S. and A.S. Dezfouli. 2019. Effects of foliar application of micronutrients on seed yield and oil quality of canola (*Brassica napus* L. cv. Hyola401) under drought stress conditions. Iran. J. Crop Sci., 21(3): 237-253. https://doi.org/10.29252/abj.21.3.237

Kanwal, S., M.A. Rahmatullah, H.F. Maqsood and S.G. Bakhat. 2009. Zinc requirement of maize hybrids and indigenous varieties on Udic Haplustalf. J. Plant Nutr., 32: 470–478. https://doi.org/10.1080/01904160802661782

Kostik, V., S. Memeti and B. Bauer. 2013. Fatty acid composition of edible oils and fats. J. Hyg. Eng. Design, 4: 112-116.

Kour, S., M. Gupta, D. Kachroo and R. Bharat. 2017. Direct and residual effect of zinc and boron on productivity, nutrient uptake and quality on mustard (*Brassica juncea*) and succeeding maize (*Zea mays*) in subtropical inceptisols of Jammu. J. Indian Soc. Soil Sci., 65(3): 334-340. https://doi.org/10.5958/0974-0228.2017.00039.1

Kumar, M., S. Singh, V. Singh, K. Singh and R. Khanna. 2019. Effect of zinc and boron on growth and yield of maize (*Zea mays* L.). Prog. Res. Int. J., 14(3): 215-221.

Mahmood, T., M. Hussain, H.S.B. Mustafa, E. Hasan and M. Aftab. 2017. Aari canola: Pakistan's first ever canola quality and short duration mustard (*Brassica juncea* L.) cultivar resilient to climate change. Int. J. Biol. Pharm. Allied Sci., 6(4): 777-787.

Malakouti, M. and M. Tehrani. 2005. Micronutrient role in increasing yield and improving the quality of agricultural products. Tarbiat Modarres Press, 46: 1200-1250.

Malakouti, M.J., 2007. Zinc is a neglected element in the life cycle of plants. Middle Eastern Russ. J. Plant Sci. Biotechnol., 1(1): 1-12.

Mehera, M.S.R.B., 2022. Effect of organic manures and micronutrients (Zn and B) on growth, yield and economics of Indian mustard (*Brassica juncea* L.). Pharma Innov. J., 11(4): 1251-1254.

Morshedi, A., and H. Naghibi. 2004. Effects of foliar application of Cu and Zn on yield and quality of canola seed (*Brassica napus* L.). J. Agric. Sci. Natl. Resour., 11(3): 15–22.

Mousavi, S.R., M. Galavi and G. Ahmadvand. 2007. Effect of zinc and manganese foliar application on yield, quality and enrichment on potato (*Solanumtuberosum* L.). Asian J. Plant Sci., 6: 1256–1260. https://doi.org/10.3923/ajps.2007.1256.1260

Mousavi, S.R., M. Galavi and M. Rezaei. 2013. Zinc (Zn) importance for crop production. A review. Int. J. Agron. Plant Prod., 4(1): 64-68.

Nataraja, T.H., A.S. Halepyati, B.T. Pujari and B.K. Desai. 2010. Influence of phosphorus levels and micronutrients on physiological parameters of wheat (*Triticumdurum* Dcsf.). Karnataka J. Agric. Sci., 19(3).

Ngozi, U.F., 2013. The role of biofortification in the reduction of micronutrient food insecurity in developing countries. Afr. J. Biotechnol., 12(37).

Pandey, N., and B. Gupta. 2013. The impact of foliar boron sprays on reproductive biology and seed quality of black gram. J. Trace Element. Med. Biol., 27(1): 58-64. https://doi.org/10.1016/j.jtemb.2012.07.003

Poddar, K.H., G. Sikand, D. Kalra, N. Wong and P.B. Duell. 2022. Mustard oil and cardiovascular health: Why the controversy. J. Clin. Lipidol., 16(1): 13-22. https://doi.org/10.1016/j.jacl.2021.11.002

Potarzycki, J., and W. Grzebisz. 2009. Effect of zinc foliar application on grain yield of maize and its yielding components. Plant, Soil Environ., 55(12): 519–527. https://doi.org/10.17221/95/2009-PSE

Qamar, R., A. Hussain, H. Sardar, N. Sarwar, H.M.R. Javeed, A. Maqbool and M. Hussain. 2020. Soil applied boron (B) improves growth, yield and fiber quality traits of cotton grown on calcareous saline soil. PLoS One, 15(8): e0231805. https://doi.org/10.1371/journal.pone.0231805

Rashid, A., E. Rafique and J. Ryan. 2002. Establishment and management of boron deficiency in field crops in Pakistan. Boron Plant Anim. Nutr. Springer, Boston, MA. pp. 339-348. https://doi.org/10.1007/978-1-4615-0607-2_34

Rashid, A.M., M.A. Yasin, Z.A. Ahmed and R. Ullah. 2006. An alarming boron deficiency in calcareous rice soil of Pakistan: Boron use improves yield and cooking quality. Proc. 3rd Int symposium on All Aspects of Plant and animal Boron Nutrition, Wuhan, China, 9-13 Sept. 2005. Spriger New York.

Rehman, A., M. Farooq, L. Ozturk, M. Asif and K.H.M. Siddique. 2018. Zinc nutrition in wheat-based cropping systems. Plant Soil, 422(1-2): 283–315. https://doi.org/10.1007/s11104-017-3507-3

Rehman, A., X. Wang, A. Hussain, R. Qamar, A. Khalofah and M. Hussain. 2022. Soil applied boron improves yield and grain quality of chickpea (*Cicerarietinum* L.) in semi-arid yermosol. J. King Saud Univ. Sci., 34(2): 101768-101776. https://doi.org/10.1016/j.jksus.2021.101768

Rehman, A.U., U.I. Ali, R. Qamar, A. Rehman, M. Hussain, H.M.R. Javeed and S. Ahmad. 2019. Boron foliage application mediates growth, oil yield and quality of sunflower in yermosols of southern Punjab. Int. J. Agric. Biol., 21(1): 209-214.

Ross, M.W., and D.R. Shuman. 1995. Micronutrient nutrition of plants. Crit. Rev. Plant Sci., 14(1): 49-82. https://doi.org/10.1080/07352689509701922

Sahito, H.A., A.W. Solangi, A.G. Lanjar, A.H. Solangi and S.A. Khuhro. 2014. Effect of micronutrient (zinc) on growth and yield of mustard varieties. Asian J. Agric. Biol., 2(2): 105-113.

Satya, S., J.G. Pitchai and R. Indirani. 2009. Boron nutrition of crops in relation to yield and quality. A review. Agric. Rev., 30: 139–144.

Shaaban, M.M., M.M. El-Fouly and A.W.A. Abdel-Maguid. 2004. Zinc-boron relationship in wheat plants grown under low or high levels of calcium carbonate in the soil. Pak. J. Biol. Sci., 7(4): 633-639. https://doi.org/10.3923/pjbs.2004.633.639

Shoja, T., M. Majidian and M. Rabiee. 2018. Effects of zinc, boron and sulfur on grain yield, activity of some antioxidant enzymes and fatty acid composition of rapeseed (*Brassica napus* L.). Acta Agric. Slovenica, 111: 73–84. https://doi.org/10.14720/aas.2018.111.1.08

Shukla, A.K., P.K. Tiwari and C. Prakash. 2014. Micronutrients deficiencies vis-a-vis food and nutritional security of India. Indian J.

Fert., 10(12): 94-112.

Sigma Plot (r)-Scientific, 2008. Data analysis and graphing software. Systat Software INC.

Silva, C.A.T., A. Cagol, T.R.B. Silva and L.H.P. Nobrega. 2011. Boron application before sowing of sunflower hybrid. J. Food Agric. Environ., 9: 580–583.

Steel, R.G.D., J.H. Torrie and D.A. Dicky. 1997. Principles and procedures of statistics. A biometrical approach. 3rd Ed. McGraw Hill Book Co., Inc., Singapore, pp. 172-177.

Tanaka, M., and T. Fujiwara. 2008. Physiological roles and transport mechanisms of boron: Perspectives from plants. Pflügers Arch. Eur. J. Physiol., 456(4): 671-677. https://doi.org/10.1007/s00424-007-0370-8

Tariq, A., S.A. Anjum, M.A. Randhawa, E. Ullah, M. Naeem, R. Qamar, U. Ashraf and M. Nadeem. 2014. Influence of zinc nutrition on growth and yield behaviour of maize (*Zea mays* L.) hybrids. Am. J. Plant Sci., 5: 2646-2654. https://doi.org/10.4236/ajps.2014.518279

Watson, D.J., 1952. The physiological basis of variation in yield. Adv. Agron., 4: 101-145. https://doi.org/10.1016/S0065-2113(08)60307-7

Welch, R.M., and R.D. Graham. 2004. Breeding for micronutrients in staple food crops from a human nutrition perspective. J. Exp. Bot., 55(396): 353-364. https://doi.org/10.1093/jxb/erh064

Wendlinger, C., S. Hammann and W. Vetter. 2014. Various concentrations of erucic acid in mustard oil and mustard. Food Chem., 153: 393-397. https://doi.org/10.1016/j.foodchem.2013.12.073

Yadav, S.N., S.K. Singh and O. Kumar. 2016. Effect of boron on yield attributes, seed yield and oil content of mustard (*Brassica juncea* L.) on an Inceptisol. J. Indian Soc. Soil Sci., 64(3): 291-296. https://doi.org/10.5958/0974-0228.2016.00041.4

Yang, M., L. Shi, F.S. Xu, J.W. Lu and Y.H. Wang. 2009. Effects of B, Mo, Zn, and their interactions on seed yield of rapeseed (*Brassica napus* L.). Pedosphere, 19(1): 53–59. https://doi.org/10.1016/S1002-0160(08)60083-1

Zhou, T., Y. Hua, Y. Huang, G. Ding, L. Shi and F. Xu. 2016. Physiological and transcriptional analyses reveal differential phytohormone responses to boron deficiency in *Brassica napus* genotypes. Front. Plant Sci., 7: 221. https://doi.org/10.3389/fpls.2016.00221