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Evaluating Different Application Methods of Silicon on Growth, Nutritional Aspects, and Yield of Barley under Rainfed Conditions

Habib Ali[1*], Muhammad Abdullah[2], Abdul Jabbar Anjum[3], Usama Numair[4], Zaryab Ali Abbass[5], Adeel Anwar[1], Husnain Jawad[6], Faisal Abbas[7]

[1]Department of Agronomy, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi 46300, Pakistan
[2]Institute of Chemical Sciences, Bahauddin Zakariya University, Multan 60800, Pakistan
[3]Department of Chemistry, University of Kotli Azad Kashmir Jammu and Kashmir
[4] Department of Horticulture, Muhammad Nawaz Sharif University of Agriculture, Multan, Pakistan
[5]Pir Mehar Ali Shah, Arid Agriculture University Rawalpindi, Pakistan
[6]Agronomic Research Institute, AARI, Government of the Punjab, Pakistan
[7]Department of Agriculture Engineering, University of Agriculture Faisalabad, Pakistan
*Corresponding Author E-mail: dradeelanwar@uaar.edu.pk

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ABSTRACT

Barley, a versatile cereal crop, is crucial for global food security due to its adaptability to diverse climates. It serves as a vital source for human consumption and livestock feed, contributing significantly to the global food supply. However, some innovative techniques are needed to enhance nutritional aspects in order to enhance the morphological and yield traits of Barley. The basic aim of this pot study was to explore the different application methods of silicon including seed priming (0 ppm, 25 ppm, 50ppm and 75 ppm) and foliar application (0 ppm, 25 ppm, 50ppm and 75 ppm) on growth, nutritional aspects and yield traits of Barley (Sultan-17). The 0 ppm dose was considered as control. The experiment was designed under CRD and repeated three times. The results showed that foliar application of silicon @75 ppm gave best growth of Barley as compared to seed priming treatments. The N, P and K of both grains and straws were significantly increased in foliar application @75 ppm as compared with control. Similarly, the yield components of Barley including biomass and grain yield were also augmented. It is suggested to apply silicon @75ppm as a foliar for better growth and yield production of Barley.

Keywords: *Silicon, barley, seed priming, foliar application, growth, nutrients, yield*

INTRODUCTION

Barley, a versatile cereal crop, is commonly grown in high altitude regions, deserts, and near the arctic circle, renowned for its safety and ease of production (Miralles et al., 2021). Barley, produced globally in fourth place after maize, wheat, and rice, is utilized in human food, animal feed, and malt drinks.

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Barley must fulfill certain requirements for grain protein, enzyme activity, kernel size and weight, and germinance before it may be malted (Zhou, 2009). Barley has few constraints when used for human and livestock food, however cultivar usage is crucial (Newton et al., 2011). Together with wheat, corn, rice, and barley, cereal crops are regarded as being among the most significant (Giraldo et al., 2019). It is an important cereal crop due to its extensive global distribution, fourth-place ranking in terms of both production amount and cultivated area among grain crops (Leff et al., 2004).

Barley's strong nutritional content has made it more popular as a diet for humans (Newman & Newman, 2006). Elevated quantities of bioactive chemicals, calcium, iron, and zinc, as well as dietary fiber can be found in whole grain barley. According to a report by the European Food Safety Authority, adults should take in 750 mg of calcium, 8-11 mg of zinc, and 8-18 mg of iron daily (Grądzki et al., 2022). When it comes to protein concentration, barley is greater (10–20%) than corn, rice bran, and wheat. Its protein is perfect for dietary supplements because it includes all the important amino acids. Barley is a great source of antioxidant polyphenols and β-glucan, two types of dietary fiber (Thondre et al., 2011). Regular beta-glucan consumption is associated with improved blood glucose and cholesterol regulation, among other health benefits. Because barley contains a high concentration of vitamin E isomers, it is also a significant dietary source of antioxidants (T. D. T. Do et al., 2015). Potential uses for vitamin E and antioxidant capacity in food are suggested by the genotype-dependent nature of these nutrients in barley(T. T. D. Do et al., 2015).

Despite being the second most common element in Earth's crust, silicon (Si) is often not considered essential for plant growth (Souri et al., 2021). However, when used, it can make a plant more resilient to environmental stressors such salt, drought, extreme temperatures, and improper nutrition. By reducing salt-induced oxidative stress and preventing water loss, silica can improve plant growth and water retention. Si can also decrease Na+ absorption and translocation, which lessens the cellular build-up of Na+ in shoot tissues (Bosnic et al., 2018). Si increases a number of photosynthetic parameters, including stomatal conductance, net CO2 assimilation rate, intercellular CO_2 concentration, and transpiration rate(Gong & Chen, 2012). According to (HABIBI, 2016), Si increases photosystem II's photochemical efficiency, photosynthetic activity, and chlorophyll concentration in maize cultivars. By enhancing culture medium with Si, this study seeks to increase plant productivity and tolerance to environmental challenges. This study assesses the effects of silicon as priming and foliar spray on growth, nutrients uptake and yield of barley plants. The hypothesis of our study is; the silicon application will improve the growth, nutrients uptake and yield of barley under rainfed conditions.

MATERIALS AND METHODS

This pot experiment was done in the earthen pots having dimensions (22 × 20 cm) at research area of department of Agronomy, PMAS-AAUR Rawalpindi, Pakistan during 2022-2023. The physiochemical characteristics of soils are listed in Table 1. Experiment was carried out in normal soils to assess the effects of silicon given as foliar spray and seed priming individually on growth, nutrients uptake, and yield of barley. The study has seven treatments T1: control, T2: 25 ppm silicon priming, T3: 50 ppm silicon priming, T4: 75 ppm silicon priming, T5: 25 ppm foliar, T6: 50 ppm foliar, T7: 75 ppm foliar. Barley seeds (sultan-17) were primed by soaking 500 g of seeds in a 1.0 L solution containing varying amounts of silicon for 12 hours, depending on the treatment, and then drying the seeds in the shade. At the flag leaf stage, three silicon foliar sprays were applied in the solution form. The recommended dose of N: P: K @ 120: 110: 70 $kgha^{-1}$, where N is applied in two splits and P and K are applied before to planting. The experiment was designed under CRD-factorial and repeated three times.

Table 1. Physiochemical properties of soil

Characteristics	Units	Values
Soil Texture	-	Sandy loam
pH	-	7.96
Ec	dS m^{-1}	5.61
SAR	(mmol $L^{-1})^{1/2}$	25.50
O.M	%	0.47
Available P	mg kg^{-1}	8.56
Extractable K	mg kg^{-1}	106.6

Statistical Analysis

The collected data on the experimental sheet was transferred to MS Excel and analyzed using Statistics 8.1. The 2-way factorial ANOVA was used to analyze the data, and the significance of the mean comparison between doses was examined using the Tukey-HSD test (Sawyer, 2009).

Plant harvesting and preparation

Each pot containing five randomly chosen plants were harvested and weighed (weight of fresh biomass) immediately using electric weight balance. Spikes were manually counted and separated, and for grain yield determination and chemical analysis, they were threshed manually. Paper bags containing (leaves and stems) were placed in a 65°C oven for three days, or until the biomass dry weight stabilized. Plant height was manually measured by using measuring tape and number of tillers were manually counted.

Chemical Analysis

About 0.1 g of the dried and crushed plant tissue samples were digested for a whole night at room temperature using 25 mL of 0.1 mol L^{-1} HNO_3 in order to determine Na and K (Subramanian, 1996). Both Na and K were measured using a flame photometer (PerkinElmer Instruments, Waltham, MA, USA). N and P were measured using 0.3 g of dried and crushed plant tissue samples digested with 1 mL of concentrated $HClO_4$ and 4 mL of concentrated H_2SO_4. Using distilled water, the digested components were quantitatively transferred to a 100 mL volumetric flask (Ryan et al., 2001). Using the distillation method and a micro-Kjeldahl device, N was computed (Devani et al., 1989). Phosphorus was measured colorimetrically at a wavelength of 750 nm using a spectrophotometer (Milton Roy Spectronic 401, Ivyland, PA, USA), as reported in (Ibrahim et al., 2016).

RESULTS

Effect silicon on growth and yield parameters

Under seed priming treatment, plant height was maximum (87 cm) in T3 (86 cm) followed by T2 (84 cm) as compared to control (83 cm); however, the variation was statistically non-significant. In case of foliar application, the maximum significant plant height (90 cm) was noticed in T7 followed by T6 (89 cm) and T5 (88 cm) over control (83 cm). In comparison to the control (4.55 t ha^{-1}), the barley biomass yield under the seed priming treatment was highest (5.28 t ha^{-1}) in T3 (5.18 t ha^{-1}), followed by T2 (4.67 t ha^{-1}); however, the change in T2 was statistically non-significant to control. When foliar treatment was used, T7 showed the highest significant biomass production (5.85 t ha^{-1}) over control (4.55 t ha^{-1}), followed by T6 (5.76 t ha^{-1}) and T5 (5.39 t ha^{-1}).

Barley grain production under seed priming treatment was highest in T4 (2.55 t ha^{-1}) and T3 (2.47 t ha^{-1}), then T2 (2.30 t ha^{-1}), relative to control (2.26 t ha^{-1}); nevertheless, the difference between control and T2 was not statistically significant. If foliar treatment was used, T7 showed the highest significant grain yield (2.85 t ha^{-1}) over control (2.26 t ha^{-1}), followed by T6 (2.81 t ha^{-1}) and T5 (2.60 t ha^{-1}). Comparing the plant numbers of tillers under the seed priming treatment to the control (254 m^{-2}), the largest numbers were found in T4 (273 m^{-2}), T3 (265 m^{-2}), and T2 (259 m^{-2}). The highest significant tillers yield (299 m^{-2}) in the case of foliar treatment was observed in T7, with T6 (295 m^{-2}) and T5 (287 m^{-2}) showing the greatest improvements over control (254 m^{-2}).

The 1000 grain weight reached its highest significant (41.63 g) under the seed priming treatment, compared to the control (37.28 g); nevertheless, the difference between other priming treatments with control were not statistically significant. When applying foliar, T7 showed the most significant 1000 grain weight (46.75 g) over control (37.28 g), followed by T6 (44.81 g) and T5 (41.94 g).

In comparison to the control (19.61 cm^2), the LAI under the seed priming treatment was highest (23.95 cm^2) in T3 (21.13 cm^2), followed by T2 (20.72 cm^2); nevertheless, the change between T3, T2 with control was not statistically significant. When foliar treatment was used, T7 had the highest significant LAI (29.18 cm^2), followed by T6 (27.07 cm^2) and T5 (25.02 cm^2), compared to the control (19.61 cm^2).

In comparison to the control (9.28 cm), the largest spike length (11.39 cm) under the seed priming treatment was observed in T3 (11.16 cm), followed by T2 (9.99 cm); nevertheless, this change between T2 and control was not statistically significant. When foliar treatment was used, T7 showed the largest significant spike length (12.11 cm), followed by T6 (11.91 cm) and T5 (11.56 cm) over control (9.28 cm).

Table 2. Effect of silicon on barley yield parameters

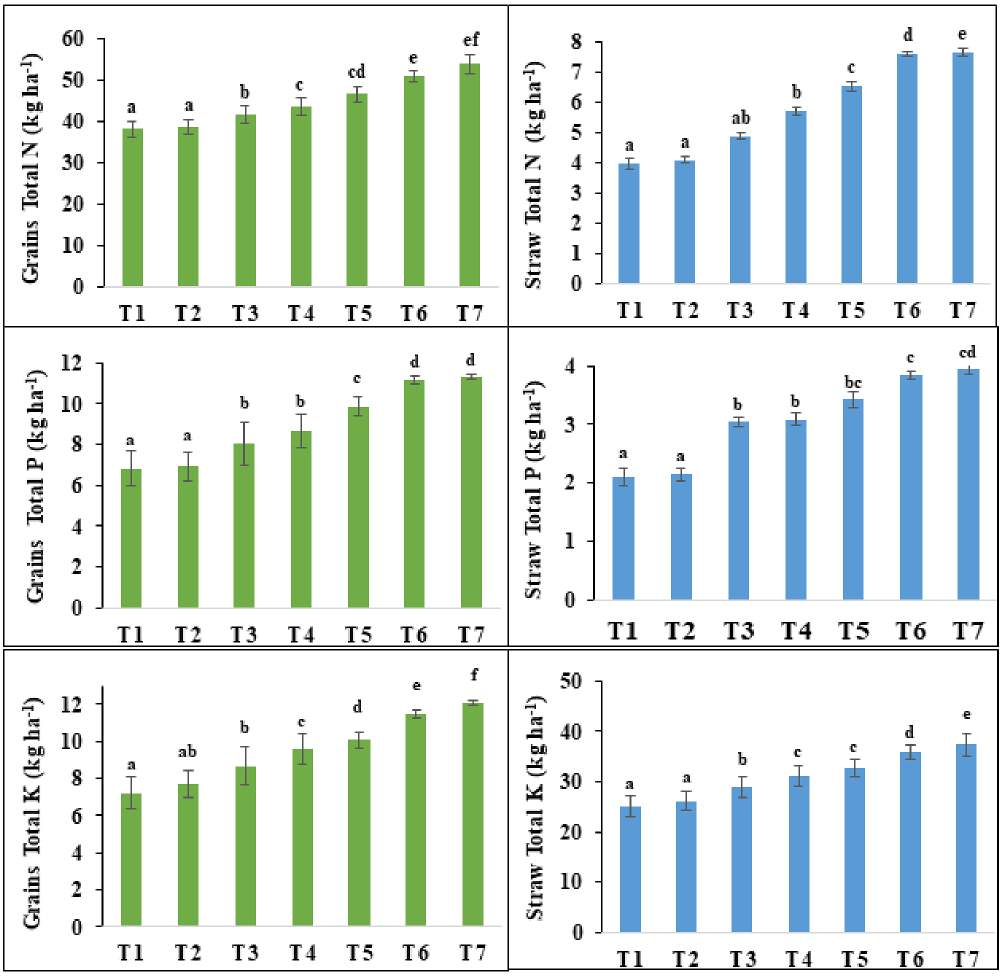
Treatments	Biomass yield (t ha^{-1})	Grain yield (t $ha^{-1)}$)	1000 grain weight (g)	Tillers (m^{-2})	Plant height (cm)	LAI (cm^2)	Spike length (cm)
T1	4.55±0.03a	2.26±0.01a	37.28±1.05a	254±14.2a	83.0±3.33a	19.61±1.62a	9.28±0.09a
T2	4.67±0.03ab	2.30±0.03ab	37.62±1.13a	259±14.4b	84.0±3.71a	20.72±1.62a	9.99±0.09a
T3	5.18±0.04b	2.47±0.04c	39.84±1.02ab	265±12.3c	86.0±3.33ab	21.13±2.41ab	11.16±1.01b
T4	5.28±0.01b	2.55±0.03cd	41.63±1.22c	273±12.7d	87.0±3.71ab	23.95±2.32b	11.39±1.01c
T5	5.39±0.06c	2.60±0.02cd	44.94±1.33d	287±10.3e	88.0±3.33b	25.02±2.41c	11.56±0.09cd
T6	5.76±0.07d	2.81±0.08e	44.81±1.03d	295±16.5f	89.0±5.13b	27.07±2.32d	11.91±0.08d
T7	5.85d±0.03e	2.85±0.04ef	46.75±1.22de	299±18.5fg	90.0±5.13b	29.18±2.41e	12.11±0.09e

Effect on N-P-K uptake

Total N uptake in barley grains under seed priming treatment was highest in T4 (43.85 $kgha^{-1}$) and T3 (41.82 $kgha^{-1}$), followed by T2 (38.68 $kgha^{-1}$), relative to control (38.22 $kgha^{-1}$); however, the difference was not statistically significant. When foliar N was applied, T7 showed the highest significant total N uptake (54.07 $kgha^{-1}$) in barley grain over control (38.22 $kgha^{-1}$), followed by T6 (51.15 $kgha^{-1}$) and T5 (46.63 $kgha^{-1}$). Total N uptake in barley straw under seed priming treatment was highest in T4 (5.69 $kgha^{-1}$) and T3 (4.88 $kgha^{-1}$), followed by T2 (4.08 $kgha^{-1}$), relative to control (3.98 $kgha^{-1}$); nevertheless, the change was statistically non-significant. When foliar treatment was used, T7 showed the highest significant total N uptake in barley straw (7.64 $kgha^{-1}$), followed by T6 (7.58 $kgha^{-1}$) and T5 (6.52 $kgha^{-1}$) over control (3.98 $kgha^{-1}$).

Comparing the total P uptake in barley grains under the seed priming treatment, the variance was statistically non-significant, with the highest uptake occurring in T4 (8.65 $kgha^{-1}$) and T3 (8.04 $kgha^{-1}$), followed by T2 (6.93 $kgha^{-1}$), while the control was (6.82 $kgha^{-1}$). The largest significant total P uptake in barley grain (11.29 $kgha^{-1}$) observed in T7, T6 (11.18 $kgha^{-1}$), and T5 (9.86 $kgha^{-1}$) over control (6.82 $kgha^{-1}$) was observed in the case of foliar treatment. In barley straw subjected to seed priming treatment, total P uptake was highest in T4 (3.08 kgha^{-1}) and T3 (3.04 kgha^{-1}), followed by T2 (2.15 kgha^{-1}), relative to control (2.09 kgha^{-1}); however, the variation was not statistically significant. Regarding foliar treatment, T7 showed the highest significant total P absorption (3.94 kgha^{-1}) in barley straw, followed by T6 (3.84 kgha^{-1}) and T5 (3.42 kgha^{-1}) over control (2.09 kgha^{-1}).

When compared to the control (7.22 kgha^{-1}), the total K uptake in barley grains under the seed priming treatment was highest in T4 (9.59 kgha^{-1}) and T3 (8.67 kgha^{-1}), followed by T2 (7.72 kgha^{-1}); nevertheless, the variation was statistically non-significant. With foliar spray, T7 showed the highest significant total K uptake (12.05 kgha^{-1}) in barley grain compared to T6 (11.47 kgha^{-1}) and T5 (10.07 kgha^{-1}) over control (7.22 kgha^{-1}). In comparison to control (25.08 kgha^{-1}), total K absorption in barley straw under seed priming treatment was highest in T4 (31.15 kgha^{-1}) and T3 (28.96 kgha^{-1}), followed by T2 (26.09 kgha^{-1}); nevertheless, the variation was statistically non-significant. When applying foliar, T7 showed the most significant total K absorption in barley straw (37.27 kgha^{-1}), followed by T6 (35.75 kgha^{-1}) and T5 (32.67 kgha^{-1}) over control (25.08 kgha^{-1}).



Post-harvest soil analysis

When the barley crop was harvested, soil analysis (Table 3) revealed a minor improvement in soil fertility parameters. When the barley crop was harvested, the extractable P and K content, organic content, and soil concentration all decreased. This indicated that the barley crop had a high nutrient uptake in saline-sodic soil and that silicon had either been administered as foliar spray or together with priming.

Table 3. Post-harvest soil analysis

Treatments	pH	EC (dS m^{-1})	Organic Matter (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})
T1	8.64±0.05a	5.66±0.04a	0.51±0.00a	10.05±0.14a	109.24±6.14a
T2	8.64±0.02a	5.64±0.05a	0.51±0.01a	10.22±0.11c	109.24±6.44a
T3	8.66±0.05a	5.64±0.03a	0.54±0.04b	10.12±0.14b	111.11±6.33b
T4	8.66±0.03a	5.63±0.00a	0.54±0.00b	10.21±0.12c	111.12±6.11b
T5	8.65±0.02a	5.61±0.05a	0.50±0.00a	10.32±0.14d	108.21±6.33a
T6	8.64±0.05a	5.60±0.04a	0.47±0.04c	10.02±0.12e	104.61±6.33c
T7	8.61±0.05a	5.59±0.05a	0.42±0.04cd	9.81±0.14f	102.01±6.21cd

DISCUSSION

Silicon (Si) is an eco-friendly substance that significantly influences plant growth and development, regulating physiological and metabolic characteristics (Gou et al., 2020; Riaz et al., 2022). However, the knowledge of different application methods to check its mechanism on plants are very important. We hypothesized that silicon application methods including seed priming and foliar application could increase growth, nutritional aspects and yield of barley. We observed that silicon foliar-applied technique is best to enhance plant growth, nutritional aspects and production metrics in the cultivation of barley.

Our study found that silicon significantly affected the uptake of nitrogen, phosphorus, and potassium by straw and barley grains. The highest N-uptake was observed in T7 (foliar spray of 75 ppm) by barley grains and straw, while the lowest was in the control group. The overall P-uptake varied from 6.82 to 11.29 kg ha-1 and from 2.09 to 3.94 kg ha-1, respectively. The total K-uptake varied from 7.22 to 12.05 kg ha-1, with the highest K-uptake at 12.05 kg ha-1 and 37.27 kg ha-1. Our study's findings, which showed that foliar spraying at 75 ppm boosted absorption (N-P-K) of barley grains and straw in normal circumstances, are compatible with those of the researchers (Raza et al., 2019; Rohanipoor et al., 2013) who came to the conclusion that N-uptake in maize was enhanced by these practices. Additionally, it was noted by (Sirisuntornlak et al., 2021) that the application of silicon enhanced the N, P, K and Ca content in biomass, enhanced the overall N-P-K absorption, and decreased the salts' toxicity.

Our study analyzed barley growth and yield components, including biomass, grain yield, 1000-grain weight, tillers m^{-2}, plant height, spike length and LAI. Our study found that silicon levels significantly impact barley yield parameters, with T7 (foliar spray @ 75 ppm) achieving the highest yields, compared to the control group with the lowest biomass. Cui et al., (2012) examined the impact of silicon (Si) on two wheat cultivars' grain quality and discovered that the application of Si had no influence on the two cultivars' 1000-grain weight or protein content also discovered that foliar spraying of silicon at prescribed N-P-K improved biomass, barley grain yield, 1000-grain weight, plant height, tillers m^{-2}, LAI and spike length. The findings corroborated the data from (Laifa et al., 2021), who discovered that applying higher quantities of silicon led to a high grain yield of barley. (Basilio-Apolinar et al., 2021). Researchers have reported that the application of silicon increased plant height (Abdelaal et al., 2020; Parveen & Ashraf, 2010; Zhu et al., 2019).

CONCLUSION

Barley growth and production have been demonstrated to be enhanced by silicon seed priming; nevertheless, foliar spraying is a more efficient technique. With this technique, silicon may be directly absorbed by leaves, enabling quick plant uptake and use. Under typical soil conditions, this technique improves barley yield components and nutrient absorption while offering prompt assistance throughout important development stages. Enhanced 1000-grain weight, biomass output, grain yield, and nutrient absorption are factors that contribute to barley cultivation's overall performance. Agronomists and farmers who want to maximize barley yield while maintaining agricultural sustainability might think about using silicon foliar spray.

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Conflict of Interest:

There is no such evidence of conflict of interest.

Author Contribution:

Habib Ali and Adeel Anwar: Conducted the experiment, collected data and write the manuscript**; Muhammad Abdullah and Abdul Jabbar Anjum:** data analysis and review the manuscript**; Usama Numair**: review and editing**; Husnain Jawad and Faisal Abbas:** data analysis, review and editing.

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