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IMPACT OF SILICA NANOPARTICLES ON WHEAT (*TRITICUM AESTIVUM* L.) VARIETIES FROM BALOCHISTAN GROWN IN SALINE SOILS

Abstract. Finding effective methods to raise salt tolerance of agricultural crops is critical for food security in arid regions. Salinity negatively affects wheat growth, reducing yield and productivity. This study aims to evaluate the impact of silica nanoparticles (Si NPs) on the growth and development of two wheat varieties from Balochistan (Azri and Shalkot) cultivated in saline soil. Seeds of Azri and Shalkot wheat varieties were collected and sown at the Balochistan Agricultural Research and Development Centre (BARDC), Quetta, under normal and saline conditions. The experiment consisted of three treatments: T1 (control) with only Nitrogen, Phosphorus, and Potassium (NPK) fertilizer; T2 with Si NPs + NPK fertilizer; and T3, where seeds were primed in Si NPs before sowing. For priming, seeds in T3 were soaked separately in water and Si NPs for 24 hours before planting. Germination was monitored for 10 to 15 days, and various growth parameters were assessed at different growth stages, including plant maturity. The wheat variety Shalkot exhibited better growth than Azri under saline stress. Silicon supplementation substantially improved plant height, spike length, chlorophyll content, spike weight, productive stems per unit area, and dry mass weight. Among the treatments, Si NP supplementation (T2) enhanced all growth parameters, while the priming treatment (T3) yielded the best results. The application of silica nanoparticles effectively enhanced wheat growth even under salt stress. This study highlights the potential of Si NPs to mitigate salinity effects and improve wheat yield, making it a promising strategy for sustainable agriculture in salt-affected regions.

Keywords: silica, nanoparticles, salinity, wheat, Balochistan

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ВЛИЯНИЕ НАНОЧАСТИЦ ДИОКСИДА КРЕМНИЯ НА СОРТА ПШЕНИЦЫ (*TRITICUM AESTIVUM* L.) ИЗ БЕЛУДЖИСТАНА, ВЫРАЩИВАЕМЫЕ НА ЗАСОЛЕННЫХ ПОЧВАХ

Аннотация. Проведена оценка влияния наночастиц диоксида кремния (Si NPs) на рост и развитие двух сортов пшеницы из Белуджистана (Azri и Shalkot), выращиваемых на засоленной почве. Эксперимент включал три варианта обработки для каждого сорта в нормальных условиях и в условиях засоления: T1 (контроль) – внесение стандартного азотно-фосфорно-калийного удобрения (NPK), T2 – внесение Si NPs совместно с NPK и T3 – предпосевная обработка семян (прайминг) в растворе Si NPs (семена отдельно замачивали в воде и в растворе Si NPs в течение 24 ч). Всхожесть семян обоих сортов отслеживали в течение 10–15 суток. Биометрические и урожайные параметры фиксировали на ключевых этапах онтогенеза, включая фазу полной спелости. Установлено, что сорт Shalkot обладает более высокой адаптивной способностью и демонстрирует лучшие показатели роста в условиях засоления по сравнению с сортом Azri. Экзогенное применение Si NPs существенно нивелировало негативное действие солевого стресса у обоих сортов. Зафиксировано достоверное увеличение высоты растений, длины и массы колоса, количества продуктивных стеблей на единицу площади, накопления сухого вещества, а также содержания хлорофилла в листьях. Сравнительный анализ вариантов обработки показал, что почвенное внесение наночастиц (T2) заметно улучшало все ростовые параметры, однако максимальная эффективность по всем исследуемым показателям была достигнута в варианте с предпосевным праймингом семян (T3). Применение наночастиц диоксида кремния эффективно улучшало рост пшеницы даже в условиях солевого стресса. Исследование демонстрирует потенциал Si NPs в снижении негативного воздействия засоления и повышении урожайности пшеницы, что делает этот подход перспективной стратегией устойчивого земледелия в регионах с засоленными почвами.

Ключевые слова: кремнезем, наночастицы, засоление, пшеница, Белуджистан

Для цитирования: Влияние наночастиц диоксида кремния на сорта пшеницы (*Triticum aestivum* L.) из Белуджистана, выращиваемые на засоленных почвах / Найяб Хина, Айеша Муштак, Фарида Бехлил [и др.]. *Vestsi Natsyyanal'nai akademii navuk Belarusi. Seryya agrarnykh navuk = Proceedings of the National Academy of Sciences of Belarus. Agrarian series*, 2026, vol. 64, no. 3, pp. 221–231 (in Russian). https://doi.org/10.29235/1817-7204-2026-64-3-221-231

Introduction. Wheat is considered a staple food and is the most essential of the three most widely produced cereal crops (wheat, rice, and maize). Wheat is annually harvested above 600 million tons. It has historically been a basic agricultural commodity [1]. The increase in wheat production in Pakistan occurred largely due to the expansion of the cultivated area, which increased from 8.9 million hectares in 2014 [2] to 9.4 million hectares in 2020 [3]. Wheat is cultivated both as a winter crop and a spring crop. However, the spring crop is less extensively grown compared to the winter crop. This is possible because of differences in variety at different places. Wheat is cultivated in tropical and subtropical areas. Wheat contains high nutritional values, but agricultural production is affected by salt accumulation [4] and almost 40,000 hectares of land are degraded annually just because of salinity in Pakistan [5]. A survey revealed that almost 6.68 M hectares of Pakistani land is wasted due to salinity [6].

The provinces of Pakistan – Sindh, Punjab, Balochistan, and KPK – have saline land (294.3, 130.4, 15.2, and 0.2 hectares respectively) [7]. Balochistan is the largest province of Pakistan by area but unfortunately it is wheat-deficient. To fulfil its wheat requirements, it has to rely on other provinces. Environmental stresses negatively affect plant growth by causing various molecular, biochemical, physiological, morphological changes in plants [8]. Environmental stresses are the factors which limit crop production in Balochistan. Basic factors include drought and cold in winter, besides these, a major abiotic factor is salinity [9–12]. It decreases wheat production in Balochistan, as salinity reduces the yield of wheat annually. It is essential to overcome such stress by employing advanced agricultural methods. Silicon supplementation is one of the best methods to control salt stress. Wheat production can be enhanced by improving fertilizers with silicon supplementation in marginal lands.

Nanotechnology represents a revolution in agriculture. Silicon nanoparticles have gained attention in advanced research because of their easy synthesis and wide applications in industries like agriculture, catalysis, pigments, pharmacy and electronic etc. [13]. Stöber introduced the synthesis of nanoparticles of 0.5–2.0 micron sized [14]. The Stöber method is the most common and approachable method used by researchers. It is applied with modifications like ultra-sonication. The literature review specifies that the Stöber method (Sol-gel method) is the easiest and most economically effective method to synthesize monodispersed, nano-sized, spherical silica particles.

Silica nanoparticles (Si NPs) can be easily synthesized by using TEOS (Tetraethyl orthosilicate) as a precursor [15]. Si NPs can be employed to increase wheat productivity. Many investigations have revealed that utilizing a small quantity of silicon can enhance the salt tolerance of soil. According to a research study, the utilization of Si NPs on 25 lentil genotypes showed beneficial results when these were grown in saline soil. Seedling growth and germination were increased [16]. There is a pressing need to apply nanotechnology to improve yield and sustain agriculture [17].

It is beneficial to apply silicon for healthy crop growth under both biotic and abiotic stress [18]. Wheat can accumulate silicon. Silicon helps to retain water in plants as well as enhance resistance against diseases. It can help maintain Na^+ and K^+ ratio in plants. Various silicon sources have been employed, out of which sodium silicate has been established as a helpful source for good growth parameters in saline environments [12–20]. It is reported that calcium silicate is a source of silicon that increases spike grains, tiller, grain yield and biological yield [21]. Other sources of silicon, like potassium metasilicate, remarkably sustain water potential in plants under saline and drought stress [22]. Silica gel boost various growth parameters such as spike length, grain yield, biological yield, relative water content, and proline content [23]. Silicon supplementation notably improves the plants efficiency under water-deficit conditions. Application of foliar spray at the time of tillering is also effective [24].

Seed priming is one of the pre-germination techniques. This technique involves soaking seeds at osmotic potential. Priming results in better growth and yield. It decreases the mean germination time. Nowadays seed priming technique is widely used [25]. Using sodium silicate in priming was found to improve the germination and seedling growth [20]. Priming seeds with Si NPs enhanced seedling shoot growth, root dry weight, seed germination, and mean germination time in wheatgrass [26].

It is vital to use silica nanoparticles for better wheat production and silica availability. As it is revealed from research that it enhances salt tolerance and give better consequences. It can support saline and drought environments. The present study investigates the synthesis of silica nanoparticles and examines their effects on the growth of two wheat varieties under salt-stressed environments. The nanoparticles were applied using two methods: direct supplementation and seed priming. Field experiments were conducted at the BARDC, Quetta.

Materials and Methods. *Silica nanoparticles synthesis.* Nanosized silica particles were synthesized by the Stöber method (modified). TEOS was utilized as a precursor. 10 ml ethanol and 4 ml DI water were mixed. In this mixture TEOS (1.8 ml) was taken in a beaker and allowed to sonicate for 60 minutes (at 35 °C). In a separate beaker NH_4OH (1.4 ml) and DI water (1.4 ml) were mixed. NH_4OH was then added dropwise to the first mixture under constant stirring. Grey color appearance indicated the formation of SiO_2 nanoparticles. These particles were centrifuged at 4,000 rpm for 20 minutes. Finally, these nanoparticles were filtered and precipitated out. Increased sonication time resulted in reduction of size. Silica nanoparticles were prepared in Sardar Bahadur Khan Women's University, Quetta, Balochistan. Silica particles were subjected to FTIR, UV and SEM.

Treatments (T) & Varieties (V): Two wheat varieties (Azri and Shalkot) were selected from BARDC, Quetta. Healthy seeds of both varieties were rinsed for control and for treatment (Table). The synthesized Si NPs were used in addition to nitrogen phosphorus potassium (NPK) fertilizer (T2) in the fields to grow wheat in saline and non-saline conditions. In priming treatment (T3), seeds were soaked separately in water and Si NPs solution for 24 hours.

Treatments and Varieties of wheat

S. No.	Symbol	Treatment & Variety
1	V_1T_1	Control of Azri
2	V_1T_2	Seeds (Azri) + Si NPs
3	V_1T_3	Seeds (Azri) + Si NPs + priming
4	V_2T_1	Control of Shalkot
5	V_2T_2	Seeds (Shalkot) + Si NPs
6	V_2T_3	Seeds (Shalkot) + Si NPs + priming

The two varieties of wheat were grown in normal soil as well as in saline soil (100 mM NaCl added in it) under all the above treatments.

Growth parameters of Wheat. Seeds of Azri and Shalkot were sown in BARDC, Quetta in the first week of October, 2022. 20 : 20 : 20 Nitrogen Phosphorus and Potassium (NPK) was used for fertilization. Germination was recorded for 10 to 15 days, observed continuously, and compared with the control. Physiological factors were also checked. Data was recorded for shoot length, spike length, spike weight, seed weight, chlorophyll content, leaf length, grains per spike, and weight of dry mass. Results of control were compared to other treatments. Data were analyzed using SPSS to calculate means and variance.

Results and Discussion. As a staple food, wheat crop is an essential cereal crop. Its demand is increasing yearly due to increase in population. So wheat yield needs to increase annually. Wheat yield is badly affected in areas, both in arid and semi-arid zones. Different factors are involved to affect its production. Salt stress is one of them. It results in a reduction in crop yield. Many areas of Balochistan and Sindh (Provinces of Pakistan) are salt-affected which in turn results in a reduction of wheat crop. To reduce salt-affected areas silica implementation is helpful which could enhance growth as well as yield of wheat in these provinces of Pakistan. Salt stress causes detrimental changes in morphology, physiology and metabolism. These changes lower plant growth. To mitigate the adverse effect of salt stress, silicon implementation is a good source [9].

The substantial role of silicon in wheat was determined in the current century. It is obvious that wheat varieties grow better by applying silicon. Its beneficial effects have been reported in wheat varieties. Wheat is a silicon accumulator [9–10]. Silicon application enhances leaf growth in wheat when compared to control in saline conditions [27, 28]. Implementation of silicon enhanced growth in wheat in saline conditions due to less intakes of sodium [29]. Silicon maintains saline tolerance in wheat and is classified as a valuable element for plant biology. It enhances potassium and decreases sodium concentration in wheat varieties grown under salt stress [30]. Application of silicon proved to enhance salinity tolerance and increase wheat production. Therefore, instead of bulk or macro silicon, the silica nanoparticles can be employed to increase availability of silicon more efficiently. So, better results can be achieved due to nanosized particles [11–12].

The current study is designed to evaluate the efficacy of silicon in agriculture and to check its effect on wheat crop growth. In this study nanosized silica particles were selected as silicon source for wheat. These nanoparticles provide valuable results in experiments when utilized in field. In earlier research, beneficial role of silicon has been noticed. Wheat is a silicon accumulator. In the presence of silicon wheat grows better [9]. In current research important growth parameters were improved, and salt stress was considerably suppressed. It established good results even in salt stress area.

In our study the silica nanoparticles were prepared through the Stöber method with few alterations. Particles were also characterized by scanning electron microscopy (SEM), ultraviolet visible spectroscopy (UV) and Fourier-transform infrared spectroscopy (FTIR). These particles were used to proceed for investigation of their effect on wheat growth in the present study. However, the results of synthesized silica nanoparticles were in agreement with prior studies in which the Stöber method with some alterations and associated with Ultrasonication generated nanosized particles in the range of 50–100 nm [9].

The current study is conducted to focus on synthesis of silica nanoparticles and their impact on wheat growth for this purpose two wheat varieties (Azri and Shalkot) were grown in normal and saline conditions in Balochistan. Silica particles were employed not only to control the salinity but also to improve the yield of wheat. In this study different growth parameters (leaf length, dry weight, fresh weight, number of grains, weight of grains and chlorophyll contents) of two wheat varieties were observed in saline and non-saline conditions. In present study, improved growth parameters were observed. Results revealed reduced salinity stress and increased tolerance. Results of silicon implementation in wheat are in accordance with earlier studies in which silicon source was calcium silicate [9].

The values of different growth parameters of replicates of two varieties in normal and saline conditions showed notable differences. Shalkot showed more resistance towards the saline environment. The final germination percentage was higher in Shalkot as compared to Azri. It was observed that growth parameters were altered in saline conditions. Plant growth was better in priming treatment as compared to direct silicon supplementation. The values of growth parameter are illustrated through bar graphs.

Growth parameters like plant height was normal in control while it was reduced in saline treatments (Figures 1, 2). When silica nanoparticles were employed in treatment V1T2 in both saline and non-saline soil all the growth parameters were improved. Application of silica nanoparticles, both via priming and direct exposure, significantly mitigated salt stress in the Azri wheat variety, resulting in an increase in plant height from 41.57 cm in the control group to 44.20 cm. In treatment where silica nanoparticles were used directly the plant height increased and better results were obtained**.** In past research plant height in rice was improved. Similarly, increased shoot length was noticed in timber species in China (Changbai larch) due to silicon application. Enhanced shoot length was also observed because of silicon effect on Basil in saline environment [9–15]. However, variation was observed in spike length (Figures 3, 4). Spike weight was observed to increase in priming treatments in both wheat varieties (Figures 5, 6). Tillers per half meter remarkably increased in priming treatments in both varieties (non-saline and saline treatments) as compared to control (Figures 7, 8). An increase in chlorophyll content was also observed in priming treatment of wheat in non-saline and saline conditions (Figures 9, 10), as this is in agreement with previous research in which chlorophyll content was increased in saline area when compared with the control [9–15]. Weight of dry mass and weight of seed grain of wheat in non-saline conditions were enhanced (Figures 11, 12). In saline soil, the values of dry mass were found better as compared to the control. These observations are similar to findings of silicon effect on Basil's weight. Therefore, it is proved that silica nanoparticles help wheat plants to survive under salt stress.

There was variation in weight of seed grain in saline condition of both varieties when compared with the control (Figures 13, 14). In past many workers found positive impacts of silicon sources on metabolism and physiology of different crops. Silicon sources increased plant height and dry mass of wheat even in saline. In a research in rice field dry matter enhanced due to silicon application. Similarly, in another research silicon implementation enhanced the yield and growth in cereals. It may be due to low uptake of sodium in the saline environment. Priming treatment with Si NPs also generated better results and seeds were found persistent in saline treatment, as priming causes breaking of dormancy of seeds faster. Better growth was observed in results when priming was done with Si NPs [9–30].

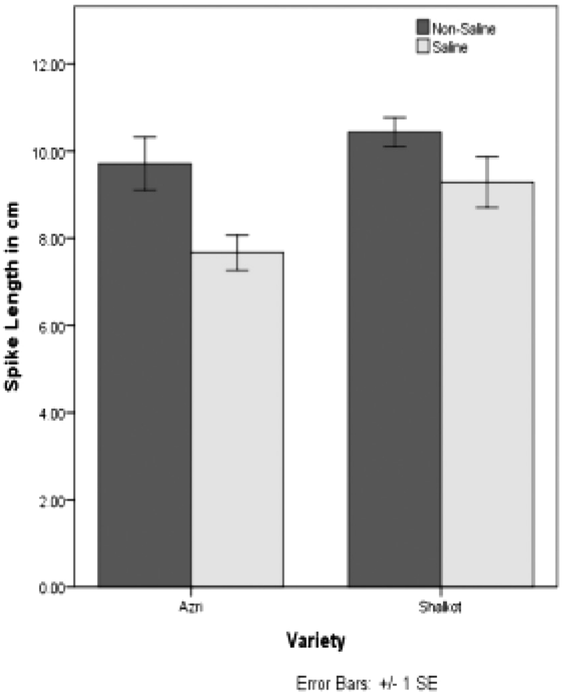

Figure 1. Spike length in two varieties

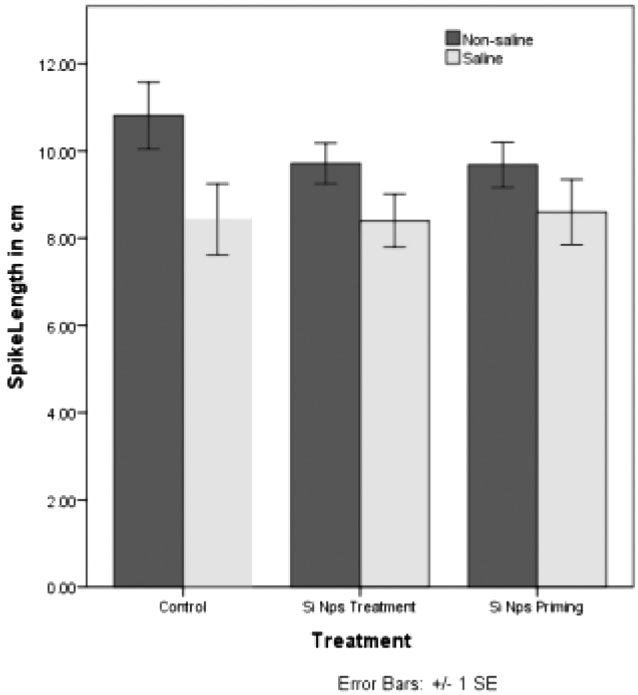

Figure 2. Spike length in different treatments

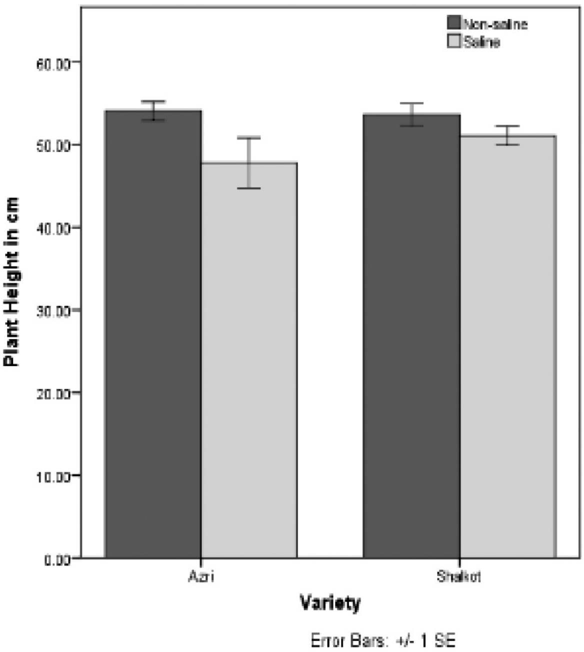

Figure 3. Plant height in two varieties

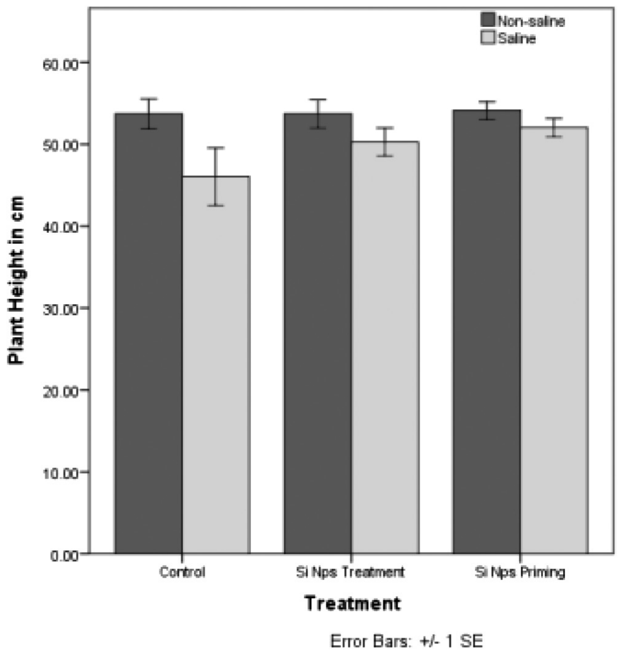

Figure 4. Plant height in different treatments

The salt-resistant variety Shalkot produced better results in presence of silica nanoparticles even in saline and non-saline conditions. When all parameters were checked, beneficial results of silica nanoparticles application were obtained even in saline stress when compared with the control. As depicted from bar graphs (Figures 1–14) growth parameter values for the control treatment (V1T1) were lower than for the treatments that included silica particles in saline and non-saline. However, treatments with silica nanoparticles priming in saline gave better results. Control values under non-saline conditions were better than control values under salt stress. In treatment T2, values of the different growth parameters were higher than in the control, even under salt stress. More substantial outcomes were attained in T2 treatments. In priming treatments (T3) much better outcomes were obtained in saline and non-saline conditions, as salt stress was reduced by priming seeds with nanoparticles at the sowing stage.

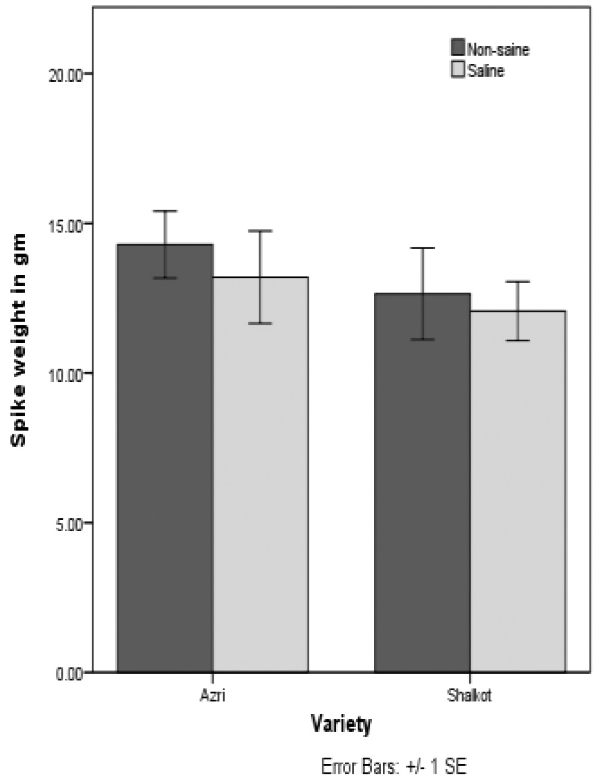

Figure 5. Spike weight in two wheat varieties

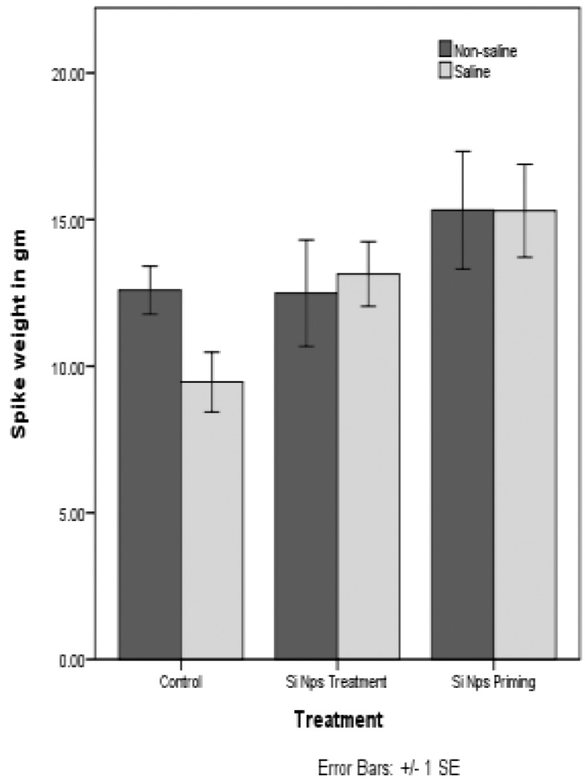

Figure 6. Spike weight in different treatmnets

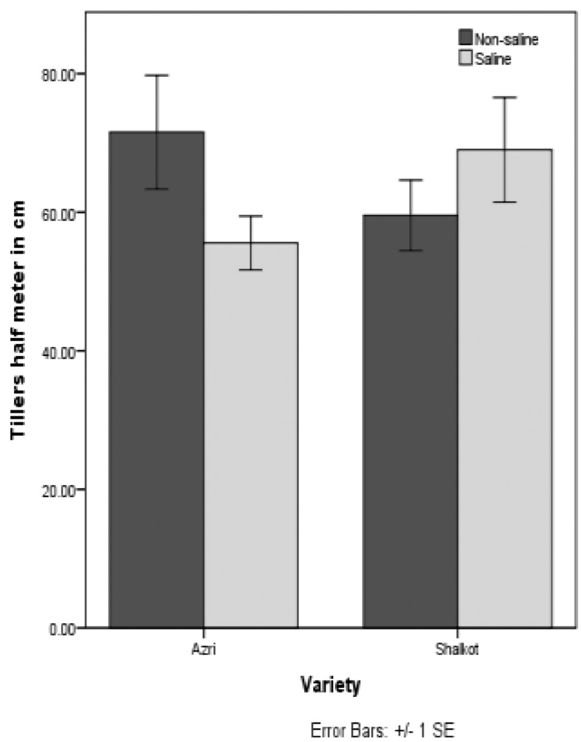

Figure 7. Tillers per half meter in two varieties

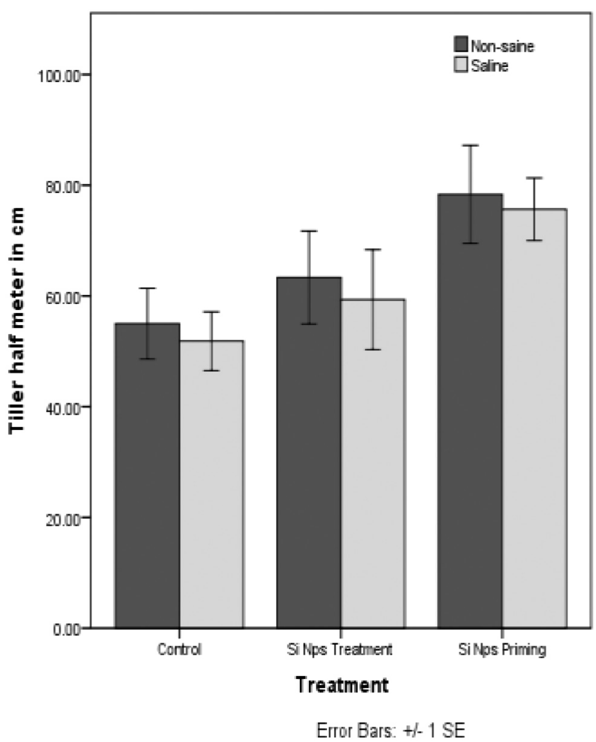

Figure 8. Tillers per half meter in different treatments

It is obvious from the results that in the absence of silica nanoparticles, growth was suppressed in saline soil while in the presence of silica, priming of seeds helped wheat mitigate the adverse effects of salinity.

Salinity reduces growth of wheat. Salinity increases sodium ion concentration and suppresses potassium absorption. It is obvious from the results that, in a controlled environment, the two wheat varieties generated

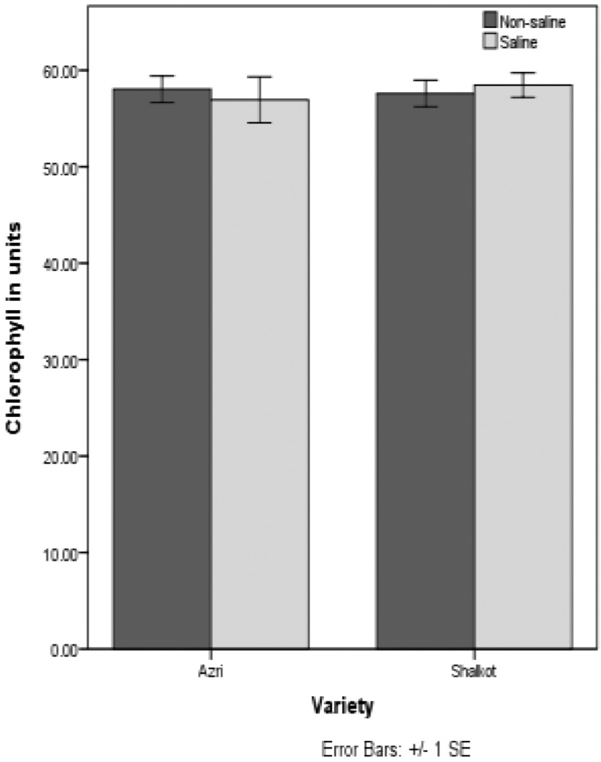

Figure 9. Chlorophyll content in two varieties

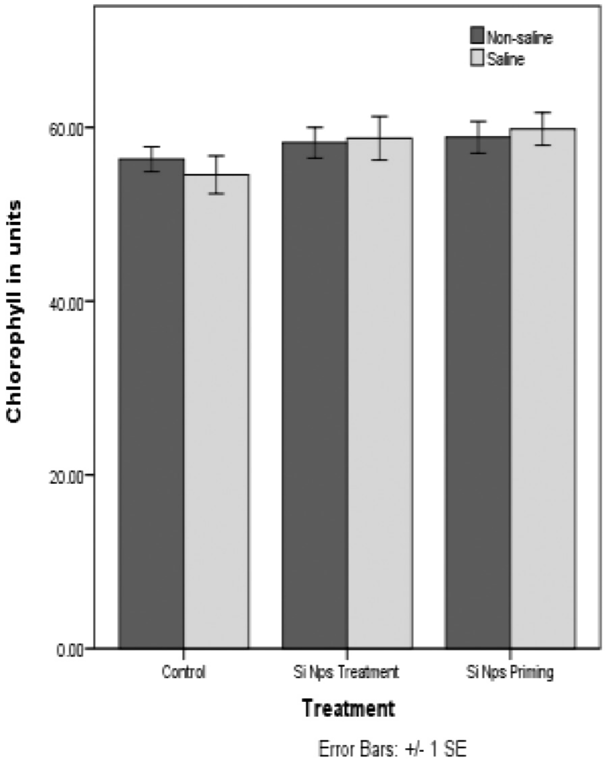

Figure 10. Chlorophyll content in different treatments

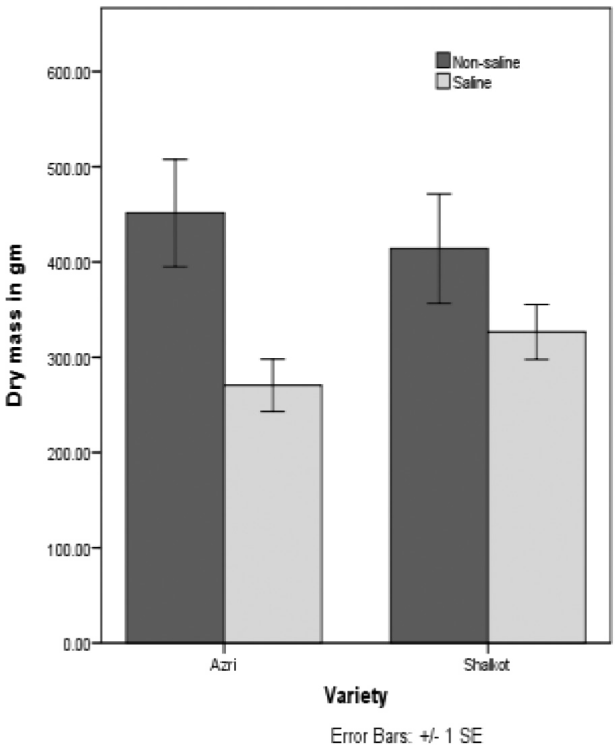

Figure 11. Dry mass in two wheat varieties

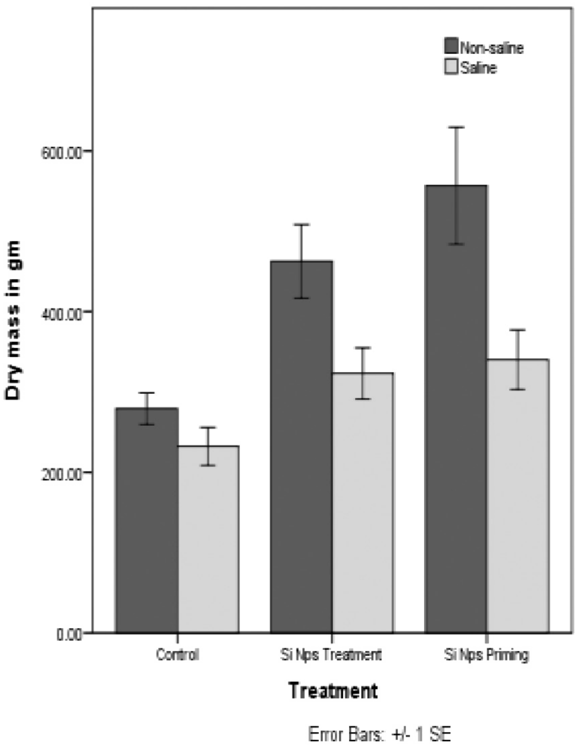

Figure 12. Dry mass in different treatments

different results in saline and non-saline conditions. Although both wheat varieties produced substantial results, Shalkot is more resistant to salt stress and gave better results of growth treatments with priming.

The current study revealed that increased concentration of salt adversely affected wheat varieties due to uptake of sodium. From the earlier studies it has been shown that employing silicon in any form can diminish the unfavorable impacts of salinity in wheat. By the induction of salt stress in two wheat

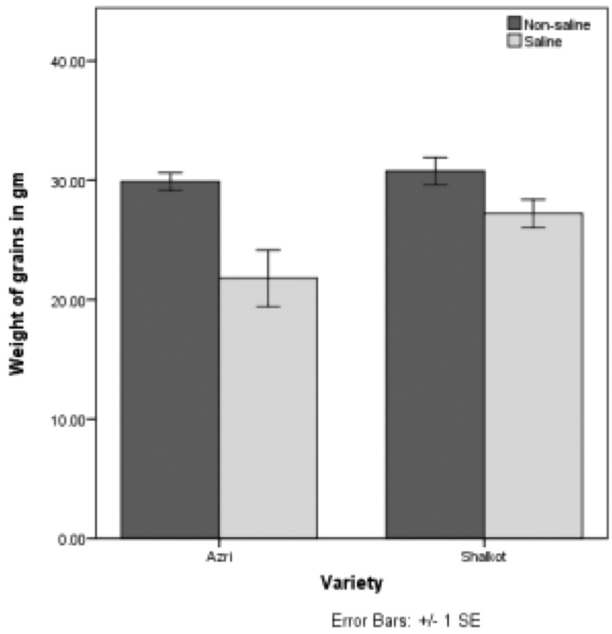

Figure 13. Weight of grains in two wheat varieties

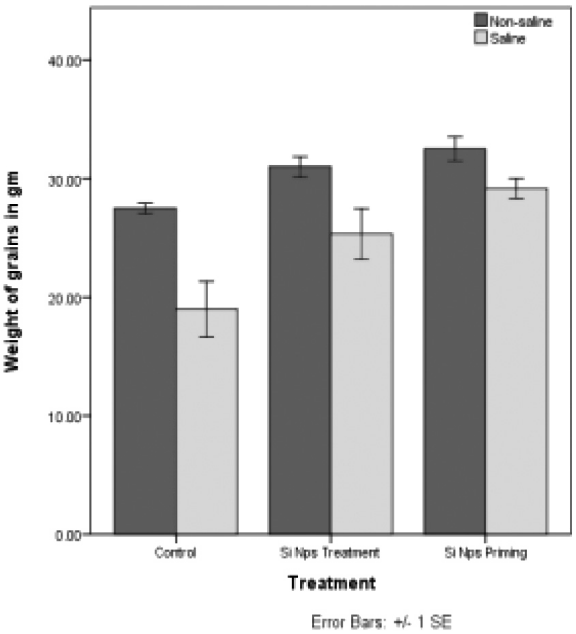

Figure 14. Weight of grains in different treatments

varieties results were in concordance with prior studies. It showed that increased uptake of sodium suppressed plant development. Silica nanoparticle supplementation helped the wheat varieties to overcome salinity stress and generated better results. It may be due to silica's hydrophilic nature as silica aids plants to store water which in turn results in more dilution of sodium in soil. Silica nanoparticles protect plant notably from adverse effect of salt as they are sources of silicon in plants. For example, sodium silicates application mitigates salinity impacts by enhancing the activity of defense-related enzymes of wheat grown in Quetta.

Application of silica nanoparticles in study has enhanced its demand in research. The valuable impact of these nanoparticles elevated the growth parameters. Results of growth parameters were in accordance with previous studies [10–34]. It is obvious from the results that silica nanoparticles reduce salinity stress with improved growth of two wheat varieties.

Principal component analysis: Principal component analysis (PCA) was carried out to analyze the selected samples of wheat varieties. PCA is a good and useful statistical technique for dimension reduction [35]. It converts high-dimensional data into smaller new variables. PCA is a multivariate method which analyzes the information table and observations are defined by many intercorrelated (dependent) variables. PCA transforms original variables which are known as principal components and are linear combinations [36].

PCA of wheat treated with silica nanoparticles revealed correlation and variance of samples grown in non-saline and saline soil. The variability in growth parameters of wheat grown in Quetta are elucidated through PCA shown in Figure 15. This elucidates the variance in data. The total three components were recognized with Eigenvalue greater than one. The first component PC1 revealed eigenvalue 2.924 followed by PC2 and PC3 having eigenvalues 1.638 and 1.049 respectively. The three components account for 80.142 % of total variance. The first component explains 41.767 % of total variance which is maximum variance by PC1 while PC2 and PC3 contribute 23.396 % and 14.979 % respectively. Spike lengths, plant height, chlorophyll, tillers per half meter, spike weight and grain weight are negatively correlated with PC1. This is similar to previous study [37]. These loadings of same sign with PC indicate positive association among these parameters of varieties [35].

PC2 was positively correlated with spike length and weight of seed grain while negatively correlated with plant height, tillers per half meter, chlorophyll, weight of dry mass. PC2 is strongly influenced by spike length and chlorophyll. It indicates longer spike length and increased seed grain weight. From the graph it is evident that PC1 and PC2 collectively explain 65 % of overall variability and are reasonably good for interpretation.

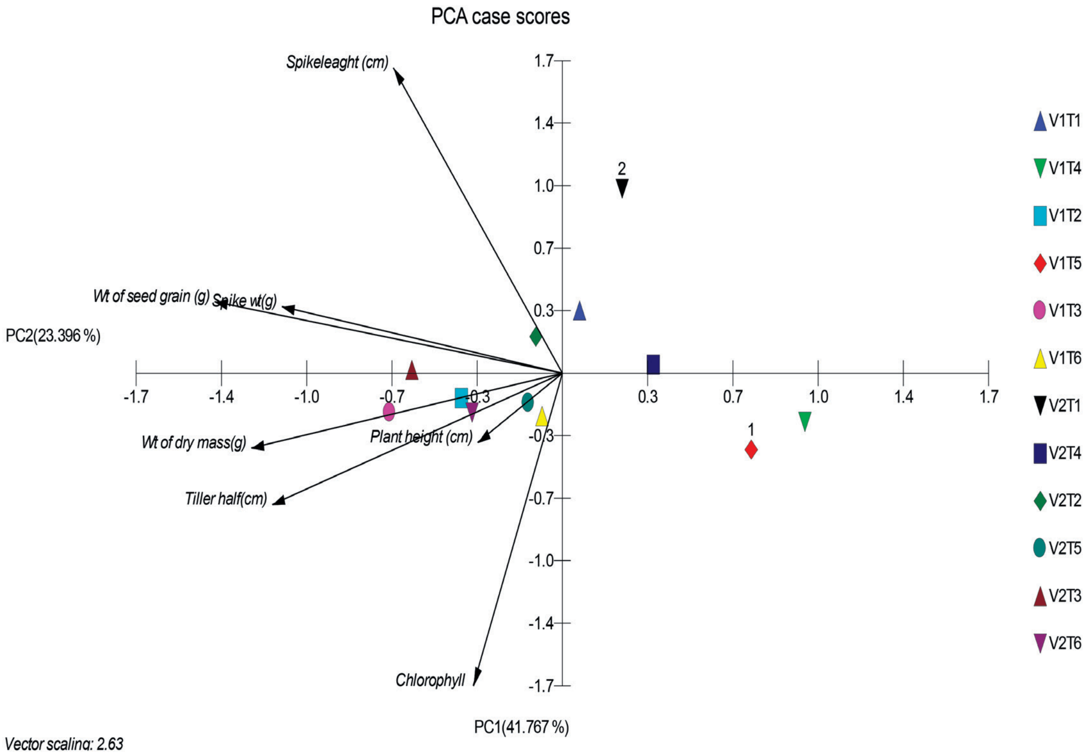

Figure 15. PCA of growth parameter of wheat grown under different treatments

PC3 is positively correlated with plant height, weight of dry mass, weight of seed grain while negatively correlated with spike length, tillers per half meter, chlorophyll, spike weight. Plant height dominates in PC3.

The plot shows several distinct groups. One group reveals that treatment V1T3, V1T2, V2T3 (with Si NPs and priming) are strongly correlated with weight of spike, weight of dry mass and weight of seed grain indicating high yield. In another V1T4 and V1T5 are present along PC1 and PC2 moderately correlated with chlorophyll content. However, chlorophyll and spike length show an inverse correlation. The varieties which show score along axis can be used to enhance yield and it can be good for physiological tolerance in wheat. Results are in agreement with previous studies.

Conclusion. This study evaluated the effects of nano-sized silica particle supplementation on two wheat varieties grown in the fields of BARDC, Quetta. The results demonstrate that silica nanoparticle supplementation substantially enhances wheat growth, even under saline stress conditions, making it a promising alternative for improving crop yield.

The findings suggest that incorporating silica nanoparticles into fertilizers, even in minimal quantities, could benefit agricultural productivity. Additionally, priming wheat seeds with trace amounts of silica nanoparticles has proven to be an effective technique, which could be introduced to farmers as a practical strategy. This approach may be particularly beneficial for wheat cultivation in salt-affected regions of Pakistan, where it can enhance crop resilience and yield. By integrating silica-based fertilization, wheat production in salt-affected areas could be improved.

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