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Silica nanoparticle: Eco-friendly Waste Having Potential for Seed Germination of Wheat (Triticum turgidumL. Var. Sham) Under Salt Stress Conditions

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Abstract:

The germination, development, and production of directly seeded agricultural products may be impacted by a variety of abiotic stresses. Silica nanoparticle seed priming may be able to reduce these external stressors. Stress brought on by salt has now become a barrier to wheat (*Triticum turgidum*) farming success. The goal of the current research was to clarify the effectiveness of seed priming with silica nanoparticles in reducing salt-induced stress in wheat plants. In this research, silica nanoparticle at three distinct concentrations—300, 600 and 900 ppm—was used for seed priming either alone or in combination with sodium chloride (2.3 and 4.6 ds/m). The application of silica nanoparticles considerably improved seedling development while salinity stress greatly decreased germination percent and seedling growth. Seed priming significantly increased shoot length (11.53%) , root length (22.76%) , seedling length (17.57%) , shoot weight (35.56%) , root weight (19.14%) , germination stress tolerance index (91.55%), shoot length stress tolerance index (11.58%), root length stress tolerance index (22.6%), shoot weight stress tolerance index (35.54%) and root weight stress tolerance index (18.12%) under high saline treatment (4.6 ds/m). The significance of nano-silica in reducing the detrimental effects of salt stress on wheat seed growth is highlighted by the current investigation. The results showed that silica nanoparticle seed priming could enhance seedling early development under salt stress.

Graphical Abstract



Keywords: Mitigation; Priming; Salinity; Silica nanoparticle.

Statement of Novelty

Silica nanoparticle wastes suit wheat germination under salt-stress circumstances. These residues were administered as seed priming prior to planting.

Introduction

Jordan, being one of the driest countries in the Middle East, is experiencing acute water shortages [1]. The current per capita water supply in the country is less than a third of what it is globally. Jordan's population is expected to grow even faster, which would exacerbate the problem by lowering per-person water availability to just 91 cubic meters. Aquifers are depleting, water demand is rising, water pollution is rising, and water resource mismanagement is continuing unabated. Water scarcity threatens Jordan's ability to produce food, grow its industries, advance economically, and improve the lives of its citizens. Water scarcity would encourage competition in water consumption across industries. Due to the shift in water demand from agricultural to household uses brought on by population growth, agriculture is an important sector that will be adversely affected by water scarcity. Furthermore, in order to meet the increased demand for irrigation, low-quality water, particularly saline water, will be used more frequently [2]. Abiotic stress is one of the most critical challenges facing agriculture today. It results in significant agricultural losses around the world, as well as a reduction in planted acreage, posing a severe danger to global food security [3]. The growth and yield of agricultural crops can be damaged by a variety of environmental stresses that plants are prone to, including water stress, salinity, extremely high temperatures, heavy metals, and others [4]. Water stress and salinity are two of the most significant environmental problems limiting agricultural productivity around the world. They are predicted to become more severe in the coming years, limiting plant growth and yield of several commercially significant species. Salinity is the key environmental stresses that limits plant growth in dry and semi-arid environments with minimal rainfall and high temperatures [5]. More than 20% of soils worldwide are damaged by salt, and the extent of these soils is growing due to human activity and climate change [6]. Incorrect agricultural land use, a lack of rain, excessive evaporation, and poor drainage are all causes of salinity. Saline soil is a term used to describe soils with salt

concentrations that impede plant growth (Ece > 4 dS/m1) as well as soils with salt concentrations that do not alter soil structure [7]. Salt stress will harm several parts of plant growth [8] . Salinity impairs the growth of plants, inhibits the development of their reproductive organs, and eventually lowers agricultural output [9]. Osmotic effect, specific ion effect, ion imbalance, and oxidative stress are some of the ways that salinity affects crops. The osmotic effect is the initial phase of salt stress [10]. Salts dissolved in the soil solution decrease the potential of the soil water. Root water uptake is hampered, causing a water shortage. Rapid root-to-shoot transmission of the water deficit signal causes a reduction in intracellular turgor and cell growth, which lowers stomatal conductance and lowers carbon uptake, biomass output, and yield. Osmotic control of stomatal conductance is quickly induced by salt shock [11].

The most important staple crops worldwide are wheat, rice, and maize, which are also a major source of daily calories and protein [12]. Due to its domestication and role as the world's main crop for staple foods, wheat is placed first among these important cereals [13]. Wheat is a staple food for about 36% of the world's population, providing approximately 20% of calories and 50% of carbohydrates, assisting in the feeding of the 4.5 billion people living in developing countries [12, 14-16] and contributing to food security.

Wheat development and growth are negatively impacted by salinity stress, which lowers grain output and grain quality [10]. Plant growth is inhibited by excessive salt concentrations, which influence several aspects of plant metabolism and result in decreased growth and yield [17]. By increasing the absorption of sodium ions, salinity stress leads to osmotic stress and ion toxicity. Salinity hinders plant growth, prevents seedling establishment, interferes with reproductive development and ultimately reduces agricultural productivity [18].

Nanotechnologies have increasingly developed in the majority of the applied sciences over the past few decades with the goal of enhancing human life, protecting the environment, and conserving the available resources [19]. Numerous sectors, including those producing cosmetics, solar energy, oil and gas recovery, food, building materials, environmental cleanup, water purification, chemicals, image contrast agents, and medications have heavily utilized nanomaterials [20].

The exceptional properties of nanomaterials made them candidates for use in the agricultural industry; they successfully produced nanoherbicides, nanofungicides, nanoscale antibacterial agents, nanoinsecticides, controlled-release fertilizers, slow-release fertilizers, DNA and gene delivery, and biosensors [21]. Protein, fertilizers, herbicides, and pesticides can all be transported by silica nanoparticles to the desired species [22]. Numerous studies have discussed the benefits of utilizing nanomaterials to improve soil fertility and plant growth [18]. Because of their tiny size, nanomaterials can directly transport the necessary nutrients to the specified organs, preventing nourishment loss through leaching or insufficient transmission [23]. In contrast to the rapid, uneven release of traditional fertilizers, nutrient encapsulation in nanomaterials enables delayed release of nutrients to the root and keeps nutrient release with plants' needs throughout the development period [24]. Water treatment and remediation has been one of the most promising environmental applications of nanotechnology. The adsorption of dyes, heavy metals, and other pollutants, the inactivation and removal of pathogens, and the conversion of harmful substances into less harmful molecules are just a few of the many ways that various nanomaterials can cleanse water [25].

Nanoparticles have the potential to penetrate the plant's cell wall and reach the plasma membrane, whereas larger particles find it difficult to get through the tiny cell pores [26]. Nanoparticles increase an organism's ability to endure water stress by enhancing plant root hydraulic conductivity and water uptake and showing differential abundance of proteins involved in oxidation-reduction, ROS detoxification, stress signaling, and hormone pathways [27]. Numerous studies have demonstrated that nanoparticles have dose-dependent biological effects on plant development and yield as well as tolerance to biotic and abiotic stresses. These effects can be both positive and negative [28-30]. Silica nanoparticle application enhanced plant tolerance to salinity stress and improved the germination of cucumber [31], *Satureja hortensis* [32]. These results have been connected to silica nanoparticle-induced improvements in the root's absorption of water and minerals. Growth indicators, especially plant height, fresh weight, nutrient return and the yield of amaranth was significantly enhanced after the foliar application of biosynthesized zinc nanoparticles [33].The formation of a binary film around the cell wall by silica nanoparticles has a significant impact on plant development [34]. The constructed wall

may lessen transpiration in plant tissues, thereby saving water and alleviating drought stress [35].

Large yields are produced because of consistent plant development, which is supported by excellent seedling vigor and successful seed germination [36]. Nano-silicon improves seed germination by making maize seeds more nutrient-available [37]. Nanoparticle seed priming is a creative and practical method for protecting plants from abiotic stress [38]. Silver nanoparticle seed priming improved the germination, growth, and yield of watermelon (*Citrullus lanatus*) seeds [39]. Nanoparticles are the perfect choice to be employed as a seed priming agent due to their small particle size (less than 100 nanometers), which has a variety of significant physio-chemical properties, such as mechanical, thermal, magnetic, electronic, optical, and catalytic capabilities [40].

The aluminum fluoride manufacturing produces a lot of waste silica when H2SiF6 is neutralized with Al(OH)3.This chemical significantly harms soil, ecosystems, and water supplies. The production of silica waste by aluminum fluoride plants poses a significant environmental and economic problem to the sector as well as environmental planners. Waste silica treatment is an expensive procedure. Therefore, the most practical way to dispose of these wastes is to use the residues in agriculture. In the current study, different concentrations of silica nanoparticles were used either as a priming agent for ameliorate the negative influence of salinity during wheat seed germination to test their impact on germination and growth after subjected to saline stress. Wheat seeds were primed to germinate under salinity stress using silica nanoparticles that were collected as refuse from an aluminum fluoride plant in Jordan. This is the first time waste silica from the aluminum fluoride company has been used in a field of crops. In addition to reducing any negative environmental effects, this could pave the way for the broad use of this waste in cultivation and potentially attract new investment.

Materials and methods

Experiment location

The experiment was carried out at AL-Huson University College-Al-Balqa Applied University in the northern part of Jordan (32°27′N, 35°27′E) in November 2021 to examine the effects of seed priming with silica nanoparticles at various concentrations on seed germination and seedling growth of wheat irrigated with saline water at various concentrations.

Silica collection and preparation

An aluminum fluoride plant in Jordan that was located 18 miles from the city of Aqaba produced silica nanoparticles as a by-product. The abandoned product underwent a succession of washes in a 8% ammonium hydroxide solution, was rinsed in distilled water until its pH was equivalent to that of the distilled water used to commence the process, and was then dried for three hours at 105°C in an oven. A plastic bag was then used to keep the silica nanoparticle for later use. Utilizing XRF and XRD analysis methods, silica particles were characterized for their chemical and mineralogical composition both before and after the washing process. Silica nanoparticle shape and size were also seen using a scanning electron microscope (SEM). Waste silica sample has a white color, a density of 1.38 g/cm3, and a typical size of 170 to 400 nm [41]. **Table 1** displays the oxidation state of discarded silica before and after washing, as determined by XRF.

Experimental treatments

The National Agricultural Research Institute provided wheat seeds for our project (NARC). Wheat (*Triticum turgidum* L.var. Sham1) seeds were sterilized for 3 min in a sodium hypochlorite solution containing active chloride (2.7%). Seeds were then thoroughly washed with deionized water to remove the chloride contents. Silicia nanoparticles were made at different concentrations (0, 300, 600, and 900 ppm). For this purpose, the required amounts of silica particles were measured and added to deionized water. Wheat seeds were

immersed in prepared mixtures of silica nanoparticles for 24 hours in the dark and at room temperature before drying to the appropriate moisture content and storing at 5 °C for subsequent experiments.

Thirty homogeneous seeds were placed into 90 mm plastic Petri plates that contained two layers of filter paper and were wet with 10 ml of either distilled water (used as the control) or various treatment solutions. There were 12 different treatment combinations, with four different Silica nanoparticle concentrations (0, 10.68, 21.36, 32.05 mM, equivalent to 0, 300, 600, and 900 mg/L) and three salt values (control, 2.3 ds/m, and 4.6 ds/m). Four replications were used in the fully randomized design of the experiment. Every three days, 5 ml of each treatment was introduced to the petri dish in order to keep it adequately moist. In the growth room, where the temperature will be set at 25 ± 0.5°C and 80% ± 1% relative humidity, Petri plates were put. When a radical length hit about 2 mm, the germination process was considered to have started, and it was supposed to be complete when no further germination took place. Investigations were conducted into the proportion of seed germination, the length of the shoot and root, the desiccated weight of the shoot and root, and the shoot: root ratio.

Analysis of Germination Parameter Data

Morphological characteristics

The lengths of the shoot and root, as well as their dry weights, were measured after fourteen days. Seedlings with short, thick, spiral-shaped hypocotyls and stunted main roots were regarded as having abnormal germination [42]. Germination percentage (which was recorded every 24 hours for fourteen days after the start of germination) were calculated using the formulas below, in accordance with Ta *et al*. [43].

Root length (RL, centimeter) and shoot height (SL, cm) were measured fourteen days after priming began in accordance with Abdelkader *et al*. [44].

$$\text{Germination percentage} = \left({}^{total\ number\ of\ seedlings\ that\ have\ germinated\ completed}/_{toal\ number\ of\ the\ seed} \right) * 100 \ldots (1)$$

$$\text{Allometry} = {}^{\text{shoot length}}/_{\text{root length}} \ldots (2)$$

Mean germination time (MGT) was computed to determine the rate of germination time-spread per day using the method of Abdelkader *et al*. [44]:

$$\text{Mean germination time} = {}^{\sum(N * D)}/_{\sum N} \ldots . (3)$$

N is the number of seeds that germinated on day D, and D is the number of days since the experiment began.

Germination energy was computed according to method of Ruan *et al*. [45]:

$$Germination\ energy = \frac{number\ of\ seeds\ that\ germinated\ after\ four\ days}{total\ number\ of\ seed\ tested} * 100 \ldots (4)$$

The germination rate index (GRI) displays the germination rate for each day of the germination interval. Greater and quicker germination is indicated by greater germination rate index. The germination rate index was calculated to evaluate the seedling vigor according to Esechie [46].

$$\text{The germination rate index} = \sum \left(\frac{GP_n}{d_n}\right) \ldots (5)$$

GP_n: germination percentage after corresponding days of sowing

d_n: Corresponding days after sowing

Physiological attributes

The following formulas were used to compute the Promptness Index, Germination Stress Tolerance Index, Shoot and Root length Stress Index, Shoot and Root Fresh Weight Stress Index, and Seedling Vigor Index (%) at the conclusion of the trial after 14 days..

The promptness index, represented by nd 2, nd4, nd6 and nd8, measures the proportion of seeds that germinate on the second, fourth, sixth, and eighth days of observation [47].

$$\text{Promptness Index} = \text{gd2}(1) + \text{gd4}(0.75) + \text{gd6}(0.5) + \text{gd8}(0.25) \ldots . . (6)$$

Where gd2, gd4, gd6, and gd8 represent the number of seeds that, correspondingly, germinated on the 2nd, 4th, 6th, and 8th day. Following the promptness index determination, the germination stress endurance index was computed [48].

Germination Stress Tolerence Index(%)

$$= ((Promptness\ Index\ \ of\ stressed\ seeds) / (Promptness\ Index\ \ control\ seeds)) \times 100 \ldots\ldots (7)$$

Shoot length Stress Index (%)

$$= \text{shoot length of stressed plant} / \text{shoot length of control plants} \times 100 \ldots\ldots (8)$$

$$\text{Stress Index for Root Length } (\%) = \text{root length of stressed plant} / \text{root length of control plants} \times 100 \ldots\ldots (9)$$

$$\text{Stress Index for Shoot Fresh weight } (\%) = \text{shoot fresh weight of stressed plant} / \text{shoot fresh weight of control plants} \times 100 \ldots\ldots (10)$$

Stress Index for Root Fresh weight(%)

$$= \text{root fresh weight of stressed plant} / \text{root fresh weight of control plants} \times 100 \ldots\ldots (11)$$

$$\text{Index of seedling vigor} = \text{germination percentage} \times \text{seedling length} \ldots\ldots (12)$$

$$\text{length of a seedling} = \text{shoot length} + \text{root length} \ldots\ldots (13)$$

Statistical analysis

Using SAS software, all measurements were statistically analyzed using the Analysis of Variance (ANOVA) for Factorial Experiment in A Randomized Complete Block Design (RCBD) protocol, and mean comparisons were performed using the Least Significant Difference test (LSD) at P 0.05 level of confidence [49].

Result

Characterization of waste silica

The chemical makeup of waste silica both before and after cleaning is displayed. Evidently, waste silica includes some contamination in addition to silica. The sample contained significant amounts of fluorine and aluminum oxide, with concentrations of 3.98% and 4.39%, respectively (Table 1).

Amorphous silica and aluminum fluoride trihydrate are both present in unwashed refuse silica, according to the XRD pattern. Figure 1 illustrates the results of testing the contents of aluminum oxide and fluoride after cleaning. Aluminum oxide and fluoride residue concentrations in the outcome are clearly different. Utilizing a 10% ammonium hydroxide solution had removal effects for fluoride and aluminum oxide that were 93% and 100% successful, respectively.

Figure 2 displays the SEM pictures of unwashed and cleaned silica fragments.The sample contained spherical silica particles in the size range of 200 to 400 nm.

Figure I : ABOUT HERE

Figure II: ABOUT HERE

Germination percentage, germination rate index, germination energy, seedling vigor index, and mean germination time

Salt stress brought on by NaCl solutions had a substantial impact on the way seedlings reacted when they were exposed to it. Raised salinity levels raised the inhibitory effects of saline stress on wheat germination, and exposing seeds to 4.6 ds/m NaCl decreased germination percentage by 14.8 % (from 90% to 76.6%) compared to the NaCl-free condition. Germination percentage was increased by 6.53% after priming with 300-ppm silica nanoparticles since treated seeds had greater germination percentages than control treatments. As expected, the 900-ppm silica nanoparticle treatments increased this parameter more than the 300-silica nanoparticle treatment (increased by 13.05%). Additionally, silica nanoparticle priming produced greater germination rate index (14.05), germination energy (20), seedling vigor index (17955), and lower mean germination time

(10) compared to unprimed seeds when the seeds were exposed to high salinity levels (Figure 3b-e).

The germination rate indicator (GRI) decreased with rising salt levels in both control and priming situations; this decrease was more evident in seedlings exposed to high amounts of silica nanoparticle priming. The germination rate index at 2.3 ds/m NaCl was 18.06 in un-primed seed (control) and was significantly greater (22.65 seed day–1) when seeds were primed with 900 ppm silica nanoparticle while at 4.6 ds/m NacL the germination rate index was 8.83 day–1 in un-primed seed (control), and was significantly greater (14.65 seed day–1) when seeds were primed with 900 ppm silica nanoparticle.

The term "mean germination time" refers to the amount of time needed for a seed to begin and finish sprouting. Mean germination time is expressed as a unit of day or, more simply, as the total number of days required for seed germination. Shorter germination times are preferable to lengthier ones, so any therapy that shortens the mean germination time will be significant and have an impact on the vitality of seedlings and, ultimately, productivity. The average germination time rose by 25% at 4.6 ds/m compared to control (distilled water) , but only by 19.88% in primed seeds (900 PPM) when exposed to the same concentration of salinity. The establishment of a uniform stand may be compromised by a delay in the meantime to germination because the delayed germination makes the seeds more susceptible to harm from predators and compromises the success of effective establishment. The average germination period of seedlings was found to be significantly affected by the application of nanosilica. Treatment with 900 PPM nano-silica reduced the time needed for full emerging from 8.45 days for control seedlings to 8.3 days. Additionally, it was discovered that nano-silica treatments for treatments exposed to salt decreased the mean germination time in contrast to control seedlings.

Figure III:ABOUT HERE

Shoot length, root length, seedling length, shoot weight and root weight

Salinity treatments had a negative impact on wheat shoot length, root length and seedling length with the lowest length of shoot (8.06 cm), root (9.04 cm) and seedling (17.47 cm) , shoot weight (0.703 g), root weight (0.47 g) found at 4.6 ds/m salinity (un-primed seed).

In contrast, the highest shoot length (8.58 cm), root length (13.83 cm), seedling length (22.41 cm), shoot weight (0.92), root weight (0.59) was obtained by control treatment in case of un-primed seed (Figure 4) . These parameters significantly increased after priming with silica nanoparticles compared to control. Silica nanoparticle seed priming had significant effects on shoot length, seedling length, shoot weight and root weight (Table 2). The shoot length rose from 8.58 cm in case of NaCl-free condition to a maximum of 9.91 cm and increased from 8.06 cm in case of 4.6 ds/m NacL to 8.99 cm when the seeds were primed with silica nanoparticles. The root length of the plants primed with silica nanoparticles increased from 13.83 cm in the NaCl-free condition to a maximum of 16.33 cm and increased from 9.04 cm to 11.54 cm with a dose of 4.6 ds/m Nacl. Seed priming with silica nanoparticle significantly enhanced shoot length (15.5% and 11.54 %), root length (21.69 % and 26.66%), seedling length (17.09 % and 17.57%), shoot weight (30.43% and 35.71%) and root weight (37.29% and 19.15%) at 0 and 4.6 ds/m respectively.

Figure IV: ABOUT HERE

Stress tolerance index parameters

The germination stress tolerance index decreased as salt stress concentration rose in both untreated and silica nanoparticle-prepared seeds. However, primed seeds were able to raise relative the highest germination stress tolerance index of 74.95% at 2.3 ds/m NaCl, while the germination stress tolerance index was lower (47.2%) at 4.6 ds/m, but a relative rise was observed as compared to untreated seeds (Figure 5). The shoot and root stress tolerance indicator was found to be significantly impacted by the salt stress level, with the impacts being proportional to the amount of stress administered. For un-primed seeds, the ability to withstand shoot and root stress declined as NaCl content rose (from 98.62% to 93.93% for the shoot and from 99.62% to 68.02% for the root), respectively. The influences of salinity on root length were significantly demonstrated at greater salinity amounts where significant variations between the levels of 2.3 ds/m and 4.6 ds/m of NaCl were recorded, while in the case of shoot length, no significant variations in shoot length stress index values were documented between the suggested stress quantities (2.3 and 4.6 ds/m). In

agreement with the abovementioned data for shoot and root length, Shoot weight stress tolerance index decreased from 96% to 76.5% with rising salinity, whereas root fresh weight stress tolerance index decreased from 93.2% to 80.79% with increasing salinity. Seed priming with silica nano particle (900 ppm) significantly increased the salinity tolerance indexes (shoot length stress index to 113.96% (2.3 ds/m) and 104.81% (4.6 ds/m)), root length stress index (102.87% (2.3 ds/m) - 83.46% (4.6 ds/m)) , shoot fresh weight tolerance index (117.02% (2.3 ds/m) -103.6% (4.6 ds/m) and root weight tolerance index (104.51% (2.3 ds/m) -95.48% (4.6 ds/m) compared with the control.

It is well known that a plant's resistance as a juvenile will reflect its resistance as an adult. Physiological indicators such as the germination tolerance index, shoot length tolerance index, root length tolerance index, shoot weight tolerance index, and root weight tolerance index can be used to study the effect of silica nanoparticle on increasing wheat's adaptability to salt. The physiological parameter values under all salt conditions were significantly enhanced by priming with silica nanoparticles (900 ppm). The results of the current study showed that silica nanoparticle therapy at high concentrations of 900 ppm was most effective in reducing the negative effects of salt and made plants tolerant of salinity up to a certain point.

Figure V: ABOUT HERE

Discussion

The seeds used in this research were of good physiological quality, as evidenced by the fact that their germination percentage (Figure 3a) was greater than the standards used (i.e., 80%) for the marketing of wheat seeds [50]. Salt stress can totally prevent seed germination at higher levels or induce a dormant state at low levels according to Singh et al. [51]. It can decrease water intake due to the medium's lower osmotic potentials and alter metabolic activity. According to de la Reguera et al. [52], Ludwiczak et al. [53], Lu et al. [54], osmotic effects, ion toxicity, or a mix of the two effects is the ways that salt stress impacts seed germination. This study demonstrate how priming seeds of wheat with silica nanoparticle can significantly enhance the germination process in saline environments. Similar to this, Steiner et al. [55] found that using priming methods could improve wheat

seed germination in saline conditions and completely counteract the effects of mild salt stress. Similar to this, inter-root exposure to silica-based nanomaterials raised the content of trace elements magnesium, copper, and zinc and enhanced the activity of aboveground catalase, boosting rice's ability to synthesize oxygen. Silica nanoparticles may have facilitated wheat seed emerging by increasing the water permeability of the seed covering, cell walls, or organelle membranes [56]. Our most recent findings agree with those published by Lu et al. [57], who noted that tomato germination percentage rose by 70.3% following application of nano-silica against control seedlings. Similarly, after treating cucumber seeds with nano-silica, a rise in emerging of 28.7% was observed [58]. A crucial step of a plant's life that is extremely responsive to its environment is germination. Thus, increased agricultural tolerance to high salt concentrations may enhance the reliability of food production under saline circumstances.

The reduced capability of water absorption by the seeds with extremely negative osmotic potential was the cause of the decline in the germination rate index in this study as explained by Uçarlı [59]. Low external water potential, ion imbalance, and particular ion toxicity are the causes of the reduced germination rate and development inhibition brought on by salt [59]. In these situations, the absorption of ions increases excessively and the intake of water decreases [60]. Osmotic stress delays germination by reducing the proportion of seeds that germinate the germination rate index, and the energy generation process through respiration [61]. One of the most crucial factors in determining ultimate plant abundance is seed germination. The experiment's findings indicate that the use of silica nanoparticle has a favorable impact on the proportion and rate of emerging in wheat. Additionally, germination rate is a strong indicator of a seedling's success in the following phases of development, where ideal circumstances may lead to a faster rate of seedling establishment [62]. The penetration of nanoparticles inside the seed is crucial for increasing seed emerging rate [63]. Silica nanoparticle may be absorbed and used by seedlings, resulting in a rise in germination. Wheat germination time was improved by the application of nano-silica. These findings were corroborated by an experiment carried out by Alsaeedi et al. [58], who found that the addition of 200 mg L-1 of nano-silica decreased the mean germination time of cucumber by 31.7%. Salinity had an impact on how quickly the seeds could absorb water, which is a necessary first stage in the sprouting process,

which caused the delay in germination time (i.e., imbibition). In order for the recovery of seed metabolic processes and development of the embryonic axis to take place during the imbibition period, it is essential that the seeds achieve an appropriate level of hydration [61]. When seeds experience osmotic stress, it takes longer for them to adapt their internal osmotic potential to the surroundings. Highly negative osmotic potential may prevent seeds from absorbing water, preventing sprouting [64]. Furthermore, because the osmotic potential of the exterior medium can influence the enzymatic reactions in the seed, the delay in sprouting is caused by the enzymatic reactions taking longer than expected [61]. Plants typically postpone initial germination and reduce the rate and overall germination in reaction to osmotic potential reduction [59].

It has been well established that the use of nanoparticles can improve seed germination and early seedling development [65-69]. In the tomato (*Lycopersicon esculentum* Mill), silica nanoparticle at modest amounts increased mean germination time, seed germination and vigor index, seedling fresh weight, and seedling dry weight, according to Siddiqui and Al-Whaibi [68]. The previous research by Janmohammadi and Sabaghnia [70], which found that silica nanoparticle increased Helianthus annuus L.'s vigor index, is somewhat supported by these results. Increased seed or seedling vigor is regarded as a positive element in plant development and germination studies because it promotes consistent plant emergence and verdant surfaces under a variety of field conditions and has a direct impact on plant performance [62]. Nanopriming, the pre-treatment of seeds with nanomaterials, may increase -amylase activity and increase the amount of soluble sugar present, promoting the rapid seedling development [71]. Our results suggest that silica nanoparticle treatments have an impact on emerging characteristics. These outcomes are in line with those of who discovered that the administration of silica nanoparticle greatly improved Marigold (*Calendula Officinalis* L.) germination percentage, germination mean time, and germination index when compared to untreated control plants [62]. In accordance with other studies, silica nanoparticle improved the germination of rice [72] and maize [73] seeds. Silica nanoparticle also had a stronger stimulation impact on corn seed germination than their bulk equivalent [74]. Silica nanoparticle-mediated rises in corn plant seed germination are attributed to increased nutrient availability to seedlings [75]. SiNPs improved seed germination traits in thyme (*Thymus kotschyanus* Boiss), including

proportion and rate of germination, length, and fresh and dry weights of root and shoot [76].

Because germinating seed shoots develop upward, silica nanoparticle may have less of an impact on shoot growth later on, explaining the varied findings for seed shoot length and root length under various interventions. Additionally, silica nanoparticle were still being applied to the roots, allowing them to continue absorbing them and growing more effectively. The results obtained in this study about the effect of salinity on shoot and root growth confirm the findings of Wu et al. [77] with their study on *E. crus*-galli , Rajabi et al. (78) with their study on sorghum (*Sorghum bicolor* (L.) , and finally by Malik et al. [8] in their study on *Lasiurus scindicus* where they indicated that the use of higher concentrations of salinity caused inhibition of shoot growth. Plant biomass declines as salt concentration and stress duration rise because salt stress hinders the development of plant cells and components and lowers photosynthetic rate and respiration [79-80] .The solution water potential is typically decreased by high salt amounts, which harms and disturbs plant physiology and has toxic effects [9]. When exposed to high salinity for an extended period of time and salt continues to build up in the leaves, the photosynthetic machinery suffers permanent damage along with a decrease in ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) activity [81]. Low external water potential, ion imbalance, and particular ion toxicity were the causes of the reduced accumulation of shoot dry matter caused by salt [82].

Silica nanoparticle may significantly increase a plant's ability to withstand salinity duress [83-85]. According to Alsaeedi et al. [86], Silica nanoparticle in cucumber improved the viability index and seed germination rate under salt exposure. The release of silica and potential internal transmission of small-sized silica nanoparticle are two mechanisms by which silica nanoparticle on wheat has a growth-promoting impact. This might be as a result of the nanoparticle large specific surface area and tiny particle size, which enable some of the nanoparticle to either penetrate the roots directly and encourage root development or to adsorb other advantageous components from the nutrient solution to simultaneously reach the roots [87].

The result is consistent with observations by Sen et al. [88] on mungbean under salt stress. It has been proposed that the positive impact of nSiO2 on nitrate reductase activity is related to enhancing germination of soybean (*Glycine max*) seeds [89], and that it is associated with plants' capacity to absorb and utilize water and nutrients by seeds [90]. The function of silica nanoparticle in controlling the water status of plants is of importance, especially in light of the fact that the osmotic impact of salt is what initially slows plant growth under salt stress [91]. Silica nanoparticle has been found to decrease the osmotic potential (more negatively) and increase the turgor pressure of tomato leaves under salt stress, which has led to the hypothesis that silica nanoparticle can increase plants' water capacity under salinity stress [92]. One of the most significant adaptation tactics of plants under salinity circumstances is to overcome the osmotic stress and physiological deficit of situations where water is restricted. According to studies on silica nanoparticle effects, seeds that are stressed by salt can perform considerably better. Silica nanoparticle may work by stopping water loss from plants by slowing down their transpiration rate. In the current study, Silica nanoparticles promoted the sprouting of wheat seeds at different salinities without having any negative impacts, likely because they enhanced the water permeability of the seed coat, cell walls, or membranes of cell organelles. Therefore, Seed priming with silica nanoparticle could help alleviate the negative effects of salinity in wheat.

Conclusion

Nanoparticles have recently seen extensive use in the farming sector due to their numerous advantages. Crop yield is largely dependent on germination because successful germination guarantees an appropriate amount of plants per cultivation area. Additionally, a strong seedling ensures healthy growth even in the presence of biotic and abiotic stressors. The significance of nano-silica for wheat seed growing under salinity stress was demonstrated in the present study. All of the germination metrics for all treated seeds with nano-silica were improved and had greater values. The 900-ppm treatment of nano-silica out of the three treatments tested—300, 600, and 900 ppm—had the greatest impact on all germination and development traits in both control and stress conditions. The highest shoot

, root and seedling length, shoot and root weight, final germination percentage, germination rate index and Stress tolerance index parameters (germination stress tolerance index ,Shoot and root length stress index , Shoot and root weight stress index) were found when nano-silica was applied with rate of 900 ppm. However, when nano-silica was applied at the same rate, the lowest mean germination period was discovered.

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Data availability

The data that support this study will be shared upon reasonable request to the corresponding author.

Declarations

Conflict of interest No conflicts of interest associated with this publication. As corresponding author, I confirm that the manuscript has been read and approved for submission by all the named authors

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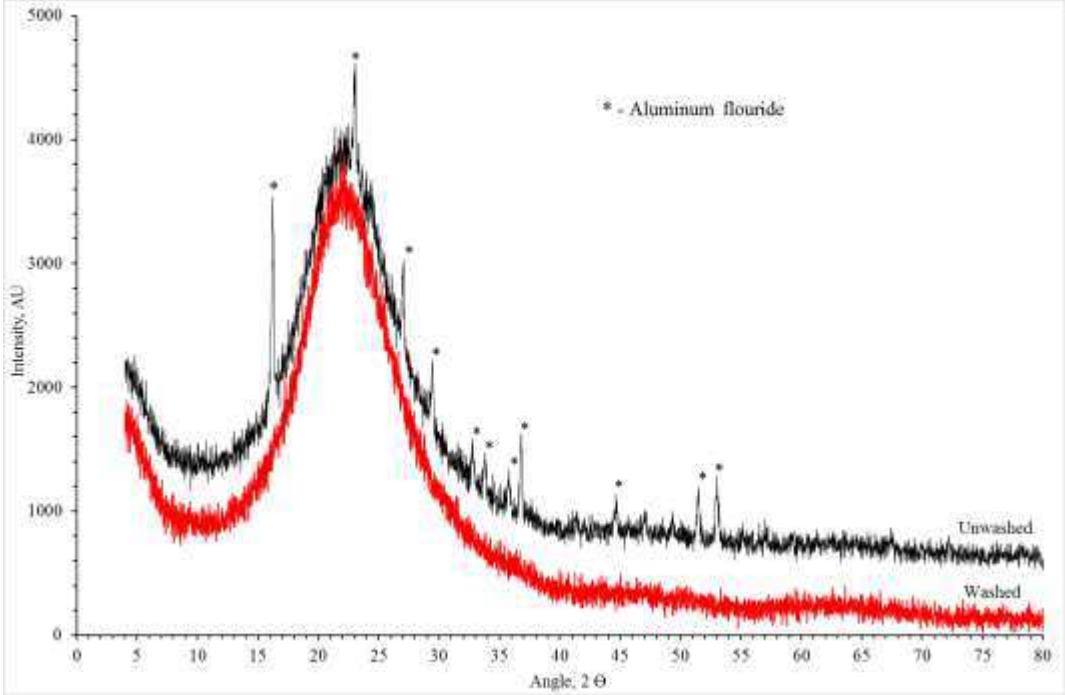


Fig.1: XRD patterns of unwashed and washed waste silica particles

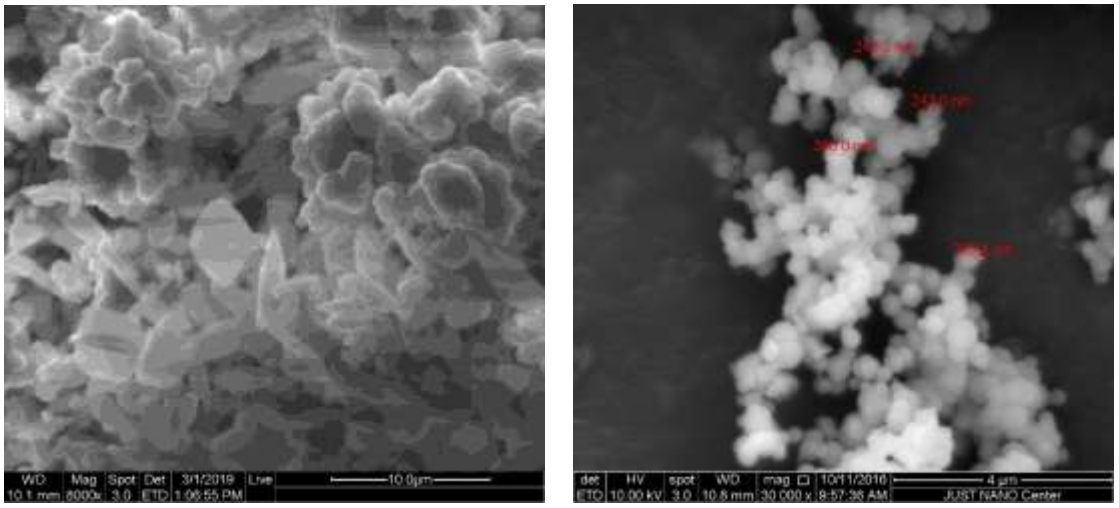


Fig. 2: SEM images of unwashed (left) and washed (right) waste silica particles

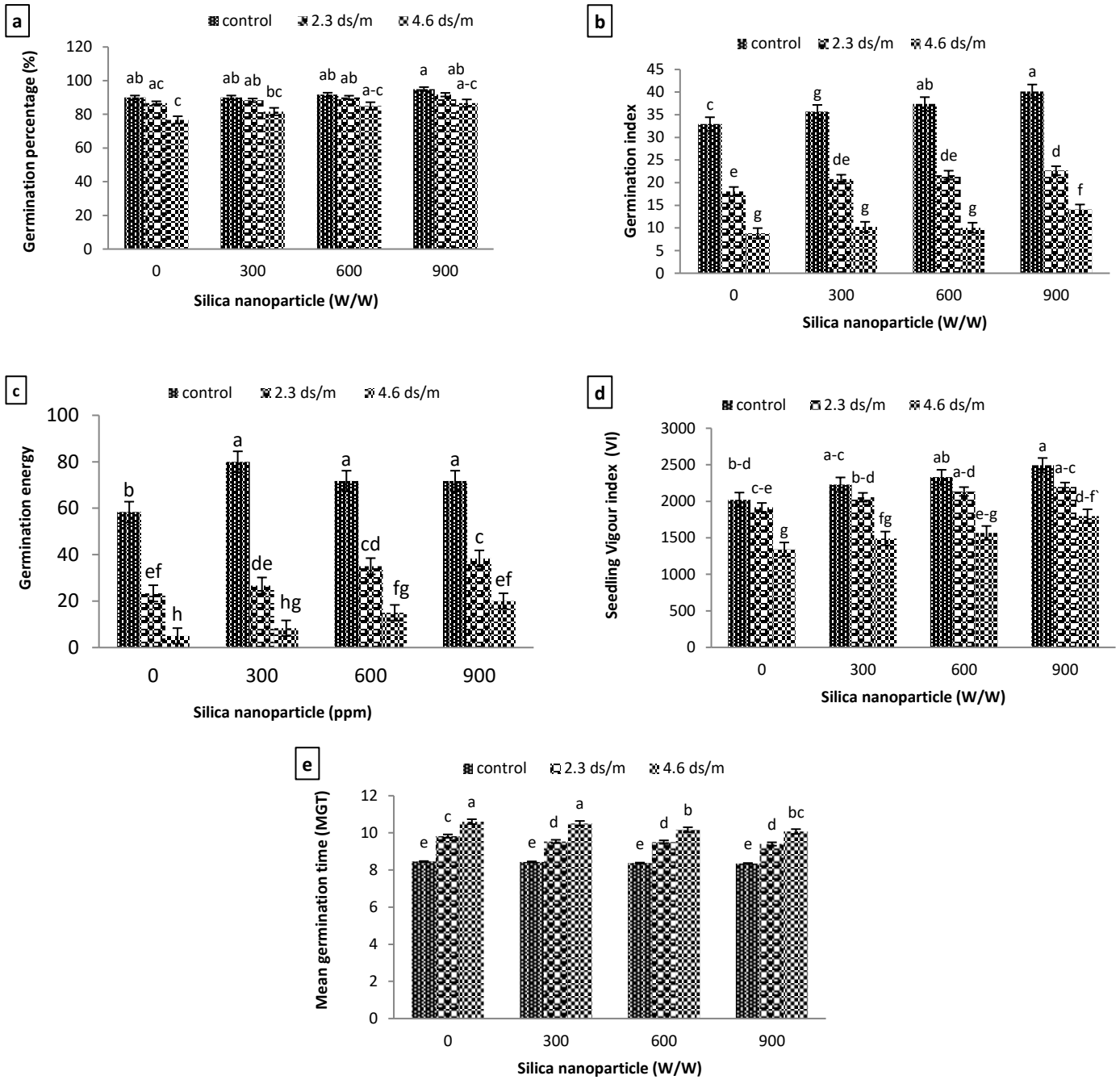


Fig. 3: Effect of seed priming with silica nanoparticle on germination percentage, germination index, germination energy, seedling vigoure index and mean germination time for wheat seed germinated under salinity stress.s. At P <0.05, bars with the same letter do not differ significantly

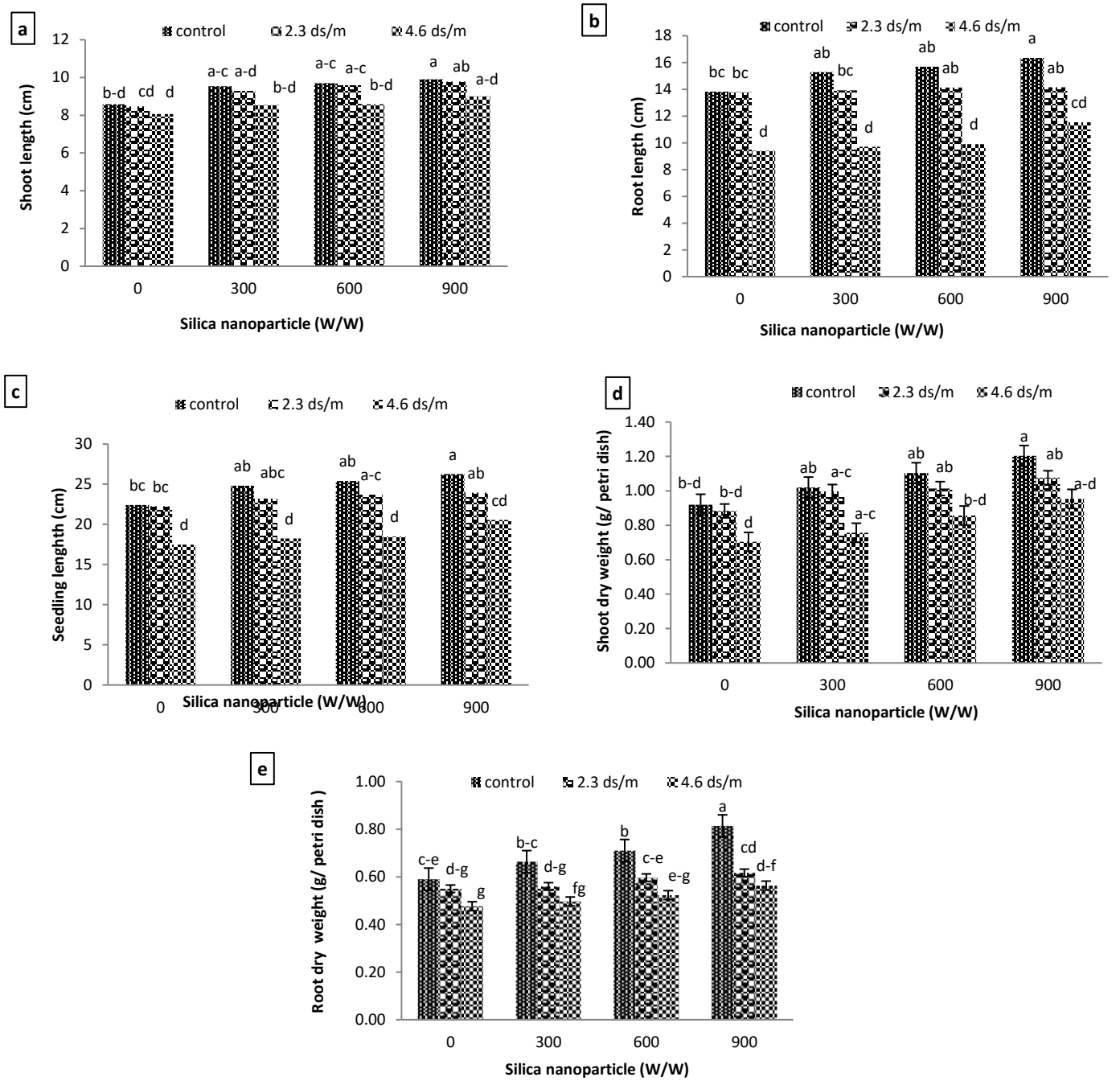


Fig. 4: Effect of seed priming with silica nanoparticle on shoot length (cm), root length (cm) , seedling length (cm), shoot : root ratio, shoot weight (g) and root weight (g) for wheat seed germinated under salinity stress. At P <0.05, bars with the same letter do not differ significantly

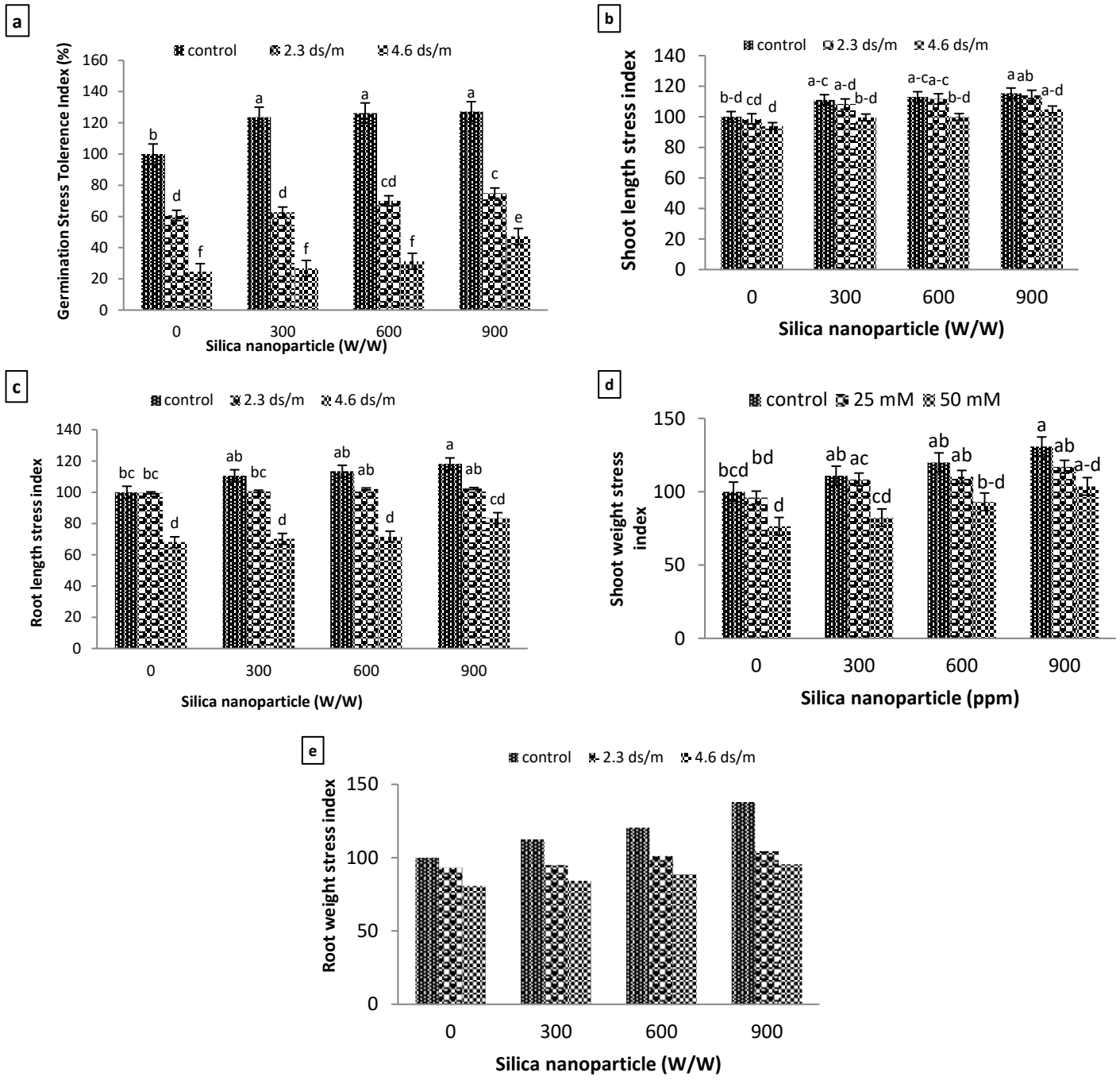


Fig. 5: Effect of seed priming with silica nanoparticle on germination stress tolerance index (%), shoot length stress index , root length stress index, shoot weight stress index and root weight stress index for wheat seed germinated under salinity stress. At P <0.05, bars with the same letter do not differ significantly.

Table 1. Oxide composition of waste silica before and after washing treatment obtained by XRF.

Oxide	Content, wt %	
	before washing	after washing
Fe_2O_3	0.2	0.3
SiO_2	78	99
Al_2O_3	4.39	0.3
F	3.98	0
LOI	13.4	0.4