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Effect of silicon and silicon nanoparticles on lead-treated wheat seedlings in hydroponic condition

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Abstract

The current study was designed to elucidate the effect of silicon and silicon nanoparticles on lead-treated wheat seedlings in hydroponic condition. Pb treatments decreased the shoot length, leaf area, shoot fresh weight, shoot dry weight, roots fresh weight and roots dry weight of wheat seedlings. The photosynthetic pigments (chlorophyll "a", chlorophyll "b", carotenoids, and total chlorophyll) were also reduced in leaves of wheat seedlings due to Pb stress. On contrary, addition of Si with Pb and addition of SiNPs with Pb successfully overcome the Pb-induced toxicity. The data showed that Si and SiNPs treatments improved the lead-treated wheat seedlings growth and photosynthetic pigments. It is concluded that Pb causes negative effect on wheat seedlings, however; Si and SiNPs protect the wheat seedlings against Pb toxicity. Further, SiNPs are more effectual than Si to ameliorate the Pb toxicity because of its greater availability to seedlings.

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Introduction

Lead (Pb) is the most common metal contaminant in terrestrial and aquatic ecosystems because of its direct release into environment, therefore, Pb can have adverse effects on plants growth and metabolism. Plants absorb lead (Pb) although, it is not an essential nutrient for them (Watanabe, 1977). Imposition of lead causes negative affect on growth and biomass of rice (Chen *et al.*, 2016). Hattab *et al.* (2016) reported that lead decreases the growth of shoot and roots of *Medicago sativa*. Venkatachalam *et al.* (2017) observed that lead causes inhibitory effects on the growth of *Acalypha indica*. Different concentration of Pb (40 ppm and 60 ppm) reduce the photosynthetic pigments such as chlorophyll "a" and "b" but increase the carotene contents (Bhatti *et al.*, 2013). Thus, it is essential to protect plants from heavy metal toxicity.

Silicon (Si) has several beneficial effects on plant growth and development. One of the beneficial effects is to increase resistance of plants to heavy metal stress. Several studies reported that Si has positive effects on plant growth and biomass under metal toxicity in nutrient solution. Under Cd stress, Si application improves the dry biomass of roots and shoots of rice and wheat plants (Tripathi *et al.*, 2012; Naeem *et al.*, 2014). Khandekar and Leisner (2011) observed an increase in biomass of wheat plants under copper and silicon treatment in hydroponic condition. Silicon and silicon nanoparticles improve the wheat growth such as increase leaf area and leaf fresh and dry biomass under UV-B stress (Tripathi *et al.*, 2017). Si treatment increases chlorophyll contents in rice under aluminium stress (Singh *et al.*, 2011). The objective of current study is to compare the effect of Si and SiNPs on *Triticum aestivum* L. under Pb stress. Wheat is an important cereal crop in Pakistan and is cultivated for grain purpose in developing countries.

Materials and methods

Preparation of Nanoparticles and Growth Medium

Silicon nanoparticles were synthesized according to the standard procedure of Zulfiqar *et al.* (2016). Sodium silicate and lead nitrate were used as a source of silicon and lead, respectively.

Grains of wheat variety Pirsabaq 2015 were sown in plastic tray containing sterilized sand. Fourteen days old wheat seedlings were smoothly uprooted from sand and roots were washed with distilled water. Then seedlings were transferred to Hoagland's nutrient solution. Thereafter, Si, SiNPs and Pb treatments were given. The treatments include: 0μM (control), 0μM + 1mM Si, 0μM + 1mM SiNPs, 25μM Pb, 50μM Pb, 25μM Pb + 1mM Si, 50μM Pb + 1mM Si, 25μM Pb + 1mM SiNPs, 50μM Pb + 1mM SiNPs. In case of Pb+Si and Pb+SiNPs treatments, seedlings were pre-treated for 24hrs with Si and SiNPs. After that, Pb treatments were added to solution. Just after treatments, seedlings were allowed to grow for 7 days. Growth medium was changed twice during growth period to avoid roots anoxia. The pH of plant growth media was adjusted to 5.8 – 5.9 by NH_4OH or HCl. Seedlings were harvested after 7 days and recorded its agronomic and photosynthetic pigments parameters.

Agronomic attributes

Growth related agronomic attributes were measured in term of shoot length, leaf area and fresh and dry biomass of shoots and roots.

Photosynthetic Pigments

Leaves were homogenized in 80% acetone and centrifuged. The absorbance of supernatant was recorded at 663.2, 646.8 and 470 nm. The amount of photosynthetic pigments (chlorophyll "a", chlorophyll "b", carotenoids, and total chlorophyll) was calculated with specified equation (Lichtenthaler, 1987).

Statistical analysis

Data were statistically analysis by using t-test. Bars indicate standard errors among replicates and means with * indicate significant differences ($P<0.05$).

Results

Silicon plays an ameliorating role in Pb toxicity by restoring growth and biomass

The data showed (Fig. 2) that Pb reduced the shoot length and leaf area of wheat seedlings. In contrast, SiNPs significantly increased the shoot length and leaf area of wheat seedlings while Si significantly increased the leaf area at 50μM + Si treatment (Fig. 2B).

Further, Si did not show significant difference at rest of the treatments. In addition, Si and SiNPs treatments alone slightly increased the shoot length and leaf area of wheat seedlings.

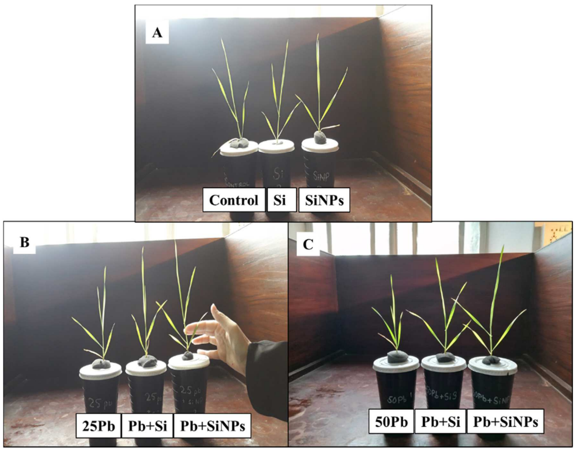


Fig. 1. Effect of Si and SiNPs on growth of wheat seedlings under lead stress.

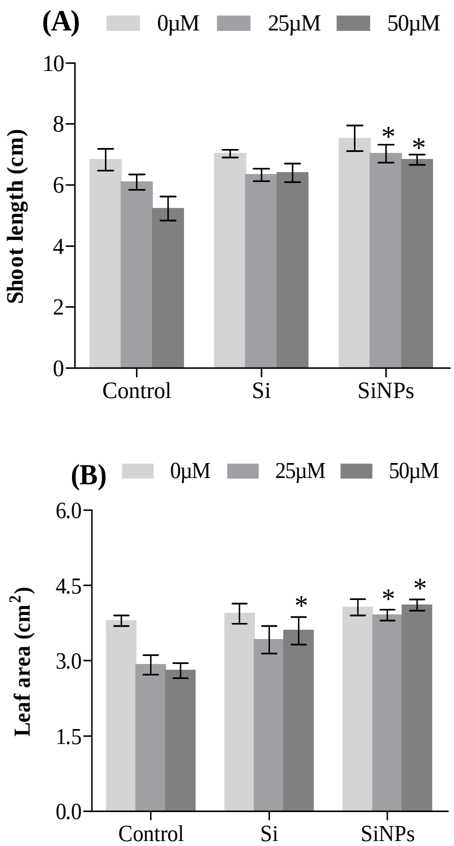


Fig. 2. Effect of Si and SiNPs on wheat (A) shoot length and (B) leaf area under Pb stress in hydroponic condition. Bars indicate standard errors among replicates and means with * indicate significant differences (P<0.05).

The results presented in Fig. 3 show that Pb reduced the shoot fresh and dry biomass. On contrary, SiNPs significantly increased the shoot fresh and dry biomass while Si significantly increased the shoot fresh and dry biomass at 25µM + Si treatment (Fig. 3). Further, Si increased the shoot fresh and dry biomass at rest of the treatments, but no significant difference was observed. In addition, Si and SiNPs treatments alone slightly increased the shoot fresh and dry biomass.

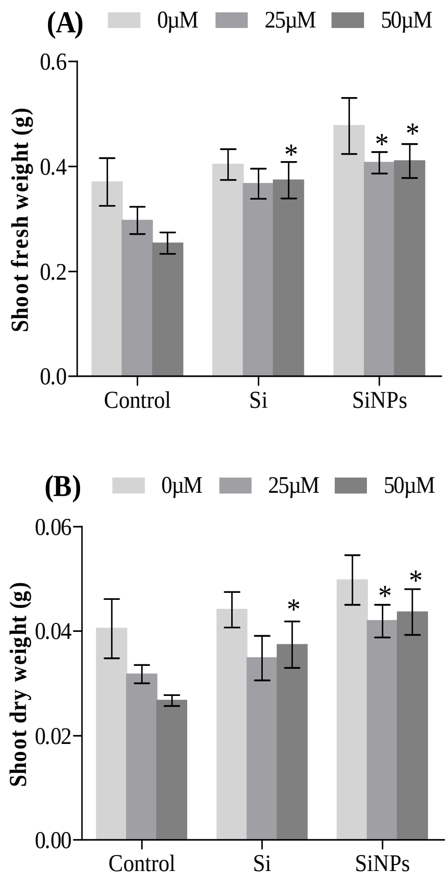


Fig. 3. Effect of Si and SiNPs on wheat shoot (A) fresh and (B) dry weight under Pb stress in hydroponic condition. Bars indicate standard errors among replicates and means with * indicate significant differences (P<0.05).

The results illustrated in Fig. 4 show that Pb reduced the roots fresh and dry biomass. On contrary, SiNPs significantly increased the roots fresh and dry biomass while Si increased the roots fresh and dry biomass, but no significant difference was observed. Further, Si and SiNPs treatments alone slightly increased the roots fresh and dry biomass.

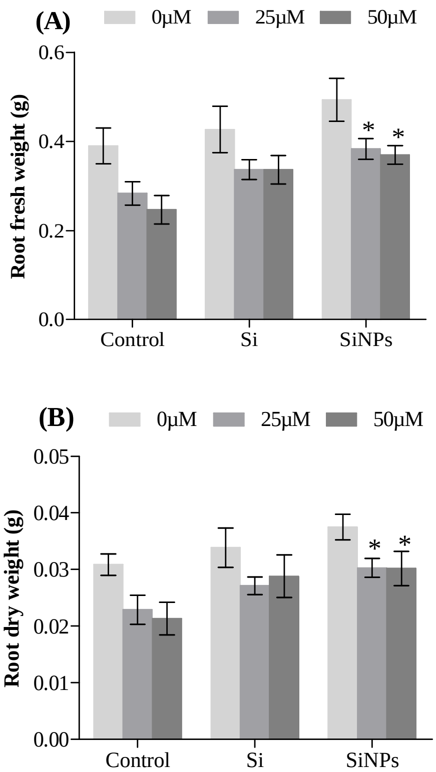
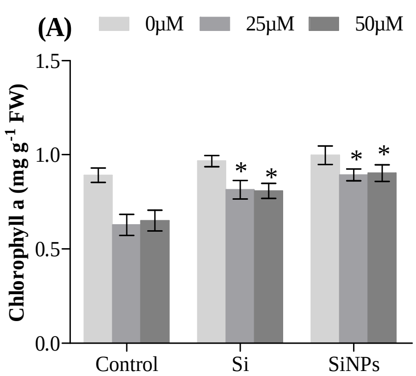


Fig. 4. Effect of Si and SiNPs on wheat root (A) fresh and (B) dry weight under Pb stress in hydroponic condition. Bars indicate standard errors among replicates and means with * indicate significant differences (P<0.05).

Silicon improves the quantity of Photosynthetic pigments in Pb-stressed plants

The data indicated (Fig. 5) that both levels of Pb stress reduced the chlorophyll "a", chlorophyll "b", carotenoids, and total chlorophyll. However, imposition of Si and SiNPs significantly improved the photosynthetic pigments under both level of lead stress. Further, Si and SiNPs treatments alone slightly increased the photosynthetic pigments of wheat seedlings.



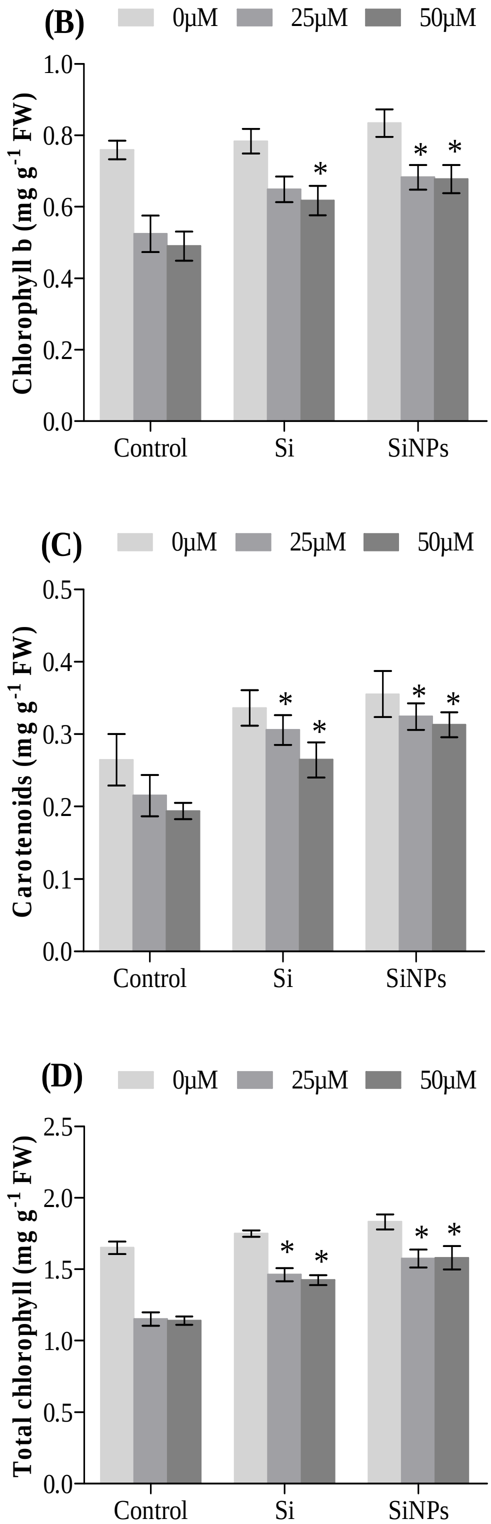


Fig. 5. Effect of Si and SiNPs on Photosynthetic pigments in leaves of wheat under Pb stress in hydroponic condition. (A) chlorophyll "a" (B) chlorophyll "b" (C) carotenoids and (D) total chlorophyll. Bars indicate standard errors among replicates and means with * indicate significant differences (P<0.05).

Discussion

The results of current study showed that Pb reduced the growth of wheat seedlings (Fig. 1-4). Similar results were also reported by Venkatachalam *et al.* (2017). He observed that lead caused inhibitory effects on the growth of *Acalypha indica*. Our results showed that Pb also reduced the photosynthetic pigments in leaves of wheat (Fig. 5). Similarly, Bhatti *et al.* (2013) and Paunov *et al.* (2018) reported that Pb different treatments reduced the photosynthetic pigments in wheat varieties. A decrease in growth may be because heavy metals trigger reactive oxygen species production. Further, the ROS damage the macromolecules and finally reduce the plant growth and alter the photosynthetic process.

However, imposition of Si and SiNPs successfully overcomes the Pb-induced decline. Si and SiNPs improved the growth and photosynthetic pigments under Pb stress (Fig. 1-5). Tripathi *et al.* (2015) reported that SiNPs increased the shoot length and photosynthetic pigments of pea under chromium stress. Tripathi *et al.* (2017) observed that Si and SiNPs improved the leaf area and photosynthetic performance of wheat plants under UV-B stress. Kopittke *et al.* (2017) reported that Si reduced the toxicity of aluminium by forming hydroxyl alumina silicate in roots of Sorghum plants. The positive effects of silicon may be because Si decreases the availability of metals in growth media which results in the reduction of the metals toxicity to plants. Further, SiNPs were more effective than Si to mitigate the Pb toxicity. Because nanoparticles have high surface area that enhances their reactivity.

Conclusion

Pb treatments decreased the growth and photosynthetic pigments of wheat seedlings. On the other hand, Si and SiNPs improved the growth and photosynthetic pigments of Pb treated plants. It is concluded that both Si and SiNPs have positive effects under Pb toxicity. SiNPs are more effective than Si to mitigate the Pb toxicity. However, further studies are needed to explore the effect of SiNPs on plants grown in metal contaminated soil.

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