



## Effect of sodium silicate on nickel toxicity in *Brassica juncea* L. seedlings

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### Abstract

Nickel (Ni) is an essential micronutrient for plants, but at elevated levels, it becomes toxic, impairing growth and metabolism. *Brassica juncea* (Indian mustard) is often used to study metal tolerance due to its phytoremediation potential. Sodium silicate ( $\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$ ), a silicon source, has been shown to mitigate heavy metal toxicity in plants. This study explores the effect of sodium silicate on *Brassica juncea* seedlings exposed to nickel toxicity, focusing on its role in reducing oxidative stress, enhancing antioxidant defense, and promoting growth under Ni-induced stress conditions.

**Keywords:** Sodium silicate, nickel toxicity, *Brassica juncea* L., seedlings

### Introduction

Population explosion and industrialization in the last few years has increased the usage of heavy metals. However, after being used up, these metals end up making their way into the environment and contaminating the natural resources like air, soil and water, from where these obnoxious metals infiltrate into the ecosystem. Plants being sessile, are unintentionally exposed to these malicious heavy metal toxicants while absorbing water and nutrients from the soil. Nickel is one of the most predominant heavy metal contaminants, which, if absorbed by the plants in optimum concentration, boosts the plant growth and metabolism. However, excess of nickel is maleficent to plant health and has been associated with decline in plant metabolism and development (Rizwan *et al.*, 2024, Hassan *et al.*, 2019) [13, 28].

Nickel associated phytotoxicity is visualized at different levels: decline in plant growth and productivity by inhibition of seed germination and retardation in root length, stem length and leaf growth (Yadav *et al.*, 2022, Shahzad *et al.*, 2018) [30, 36], impaired photosynthetic efficiency (Hassan *et al.*, 2019) [13], hindered uptake of essential phytonutrients (Mustafa *et al.*, 2023) [22], disruption of plant water relations and induction of oxidative stress (Bhalerao *et al.*, 2015) [7].

*Brassica juncea* is an economically important crop especially when it comes to the category of edible oil (Verma *et al.*, 2023) [35]. Mustard oil contains an advantageous ratio of omega-3 to omega-6 fatty acids (Manchanda and Passi., 2016) [21], and a lot of antioxidants such as alpha tocopherol, which explains why it is considered a healthy edible oil (Rai *et al.*, 2022) [25]. In addition to its nutritional and industrial uses, *Brassica juncea* is a key player in phytoremediation of heavy metal contaminated soils especially cadmium, lead and nickel (Rani *et al.*, 2023) [26]. Because of these features, it is a very helpful crop in those areas where heavy metal pollution is a problem.

Till date, a number of studies have reported the essentiality of nickel as a micronutrient (Sagwal *et al.*, 2023, Fabiano *et al.*, 2015) [9, 29] as well as its phytotoxicity in different plant species (Mustafa *et al.*, 2023, Fargašová., 2008) [10, 22].

Infact, in our previous study, we have reported augmentation of plant growth and development in *Brassica juncea* at low nickel doses, followed by abrogation of plant metabolism at high nickel doses (Yadav *et al.*, 2022) [36]. The current study is an extension of our previous study which showcases the expansion of antioxidant system at low Ni doses followed by toxicity at high doses. The present study also highlights the amelioration of Ni-induced oxidative phytotoxicity by sodium silicate by restoration of antioxidant enzyme activity. Different parameters have been analysed in this research to prove the above-mentioned hypothesis.

### Material and Methods

**Treatment of Nickel ( $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ ) and Sodium silicate ( $\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$ ):** For analysing various growth parameters, surface sterilised, uniform sized, soaked healthy seeds of *Brassica juncea* L. (var. Giriraj) obtained from ICAR-DRMR (Directorate of Rapeseed-Mustard Research, Sewar, Bharatpur, Rajasthan) were sown in pots filled with autoclaved sand and placed in dark for 3 days. After germination, seedlings were placed under natural environmental conditions in the Department of Botany, University of Rajasthan, Jaipur. The germinating seedlings were thinned to obtain five uniform sized healthy seedlings per pot. Seedlings were allowed to grow for 14 days after sowing (DAS). During this period, the seedlings were supplemented exogenously with half strength Hoagland nutrient medium (pH-6.5) together with different concentrations (0, 500, 1000 and 1500  $\mu\text{M}$ ) of nickel (Ni) in the form of ( $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ ) and sodium silicate ( $\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$ ), alone and in combination (according to the scheme of treatment given in Table 1). All treatments were exogenously supplied to soil in the form of solution. The seedlings were supplemented with 20 ml of nutrient medium every day for the next 15 days. The control (untreated) seedlings were supplemented with Hoagland nutrient medium only. Each treatment set was maintained in triplicate. Seedlings were harvested 30DAS and different parameters were analysed in treated and control seedlings.

**Table 1:** Details of treatment given for the experiment

S. No.	Treatment name	Treatment
1	Control	Only Hoagland medium
2	T1	500 $\mu\text{M}$ Ni
3	T2	1000 $\mu\text{M}$ Ni
4	T3	1500 $\mu\text{M}$ Ni
5	T4	50 $\mu\text{M}$ Si
6	T5	500 $\mu\text{M}$ Si
7	T6	500 $\mu\text{M}$ Ni + 50 $\mu\text{M}$ Si
8	T7	500 $\mu\text{M}$ Ni + 500 $\mu\text{M}$ Si
9	T8	1000 $\mu\text{M}$ Ni + 50 $\mu\text{M}$ Si
10	T9	1000 $\mu\text{M}$ Ni + 500 $\mu\text{M}$ Si
11	T10	1500 $\mu\text{M}$ Ni + 50 $\mu\text{M}$ Si
12	T11	1500 $\mu\text{M}$ Ni + 500 $\mu\text{M}$ Si

### Determination of growth and photosynthetic pigments

After 15 days of Ni and sodium silicate treatment (i.e. 30DAS), control and treated seedlings were uprooted and washed thoroughly with distilled water, blotted dry and their final root length, shoot length was recorded. For the estimation of pigments (chlorophyll and carotenoids), 20 mg fresh leaves were extracted with 80% (v/v) acetone and optical density of the supernatant was measured at 663.2, 646.5 and 470 nm spectrophotometrically using 80% acetone as blank (Lichtenthaler and Wellburn, 1983) [20].

### Indices of Oxidative stress:

**Estimation of hydrogen peroxide:** Hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) content in each sample was estimated by following the method Velikova *et al.* (2000) [34]. The absorbance of the solution was read at 390 nm against blank and the level of hydrogen peroxide in each sample was calculated from standard curve prepared with  $\text{H}_2\text{O}_2$ . The amount of  $\text{H}_2\text{O}_2$  in each sample is expressed as  $\text{nmol g}^{-1}$  FW.

**Estimation of lipid peroxidation:** Lipid peroxidation in leaves of each sample was measured as MDA (malondialdehyde) equivalents content by the method of Heath and Packer (1968) [8]. Absorbance of the supernatant was read at 532 nm and 600 nm. The value for non-specific absorption of each sample at 600 nm was subtracted from absorption recorded at 532 nm. The MDA equivalents concentration was calculated using the extinction coefficient  $155 \text{ mM}^{-1} \text{ cm}^{-1}$  and expressed as  $\text{nmol g}^{-1}$  FW.

### Antioxidant System

**Catalase:** Catalase activity was determined by the method of Aebi (1984) [2]. The absorbance of the solution was recorded at 240 nm by UV—VIS spectrophotometer for 1 min at room temperature. The consumption of  $\text{H}_2\text{O}_2$  was calculated using the extinction coefficient ( $\epsilon=39.4 \text{ mM}^{-1} \text{ cm}^{-1}$ ). One unit of CAT activity is the amount of enzyme dissociating  $1 \text{ nmol H}_2\text{O}_2 \text{ min}^{-1}$ .

### Ascorbate peroxidase (APX) activity-

Ascorbate peroxidase (APX; EC 1.11.1.11) activity in leaves of each set was estimated by the method described by Nakano and Asada (1981) [23]. The absorbance of the solution was recorded at 290 nm by UV—VIS spectrophotometer for 1 min at 25 °C. The activity of ascorbate peroxidase was measured using the extinction coefficient ( $\epsilon=2.8 \text{ mM}^{-1} \text{ cm}^{-1}$ ). One unit of APX activity is the amount of enzyme oxidizing  $1 \text{ nmol ascorbate min}^{-1}$ .

**Estimation of proline:** Total proline was estimated by the method of Bates *et al.*, (1973) [5].

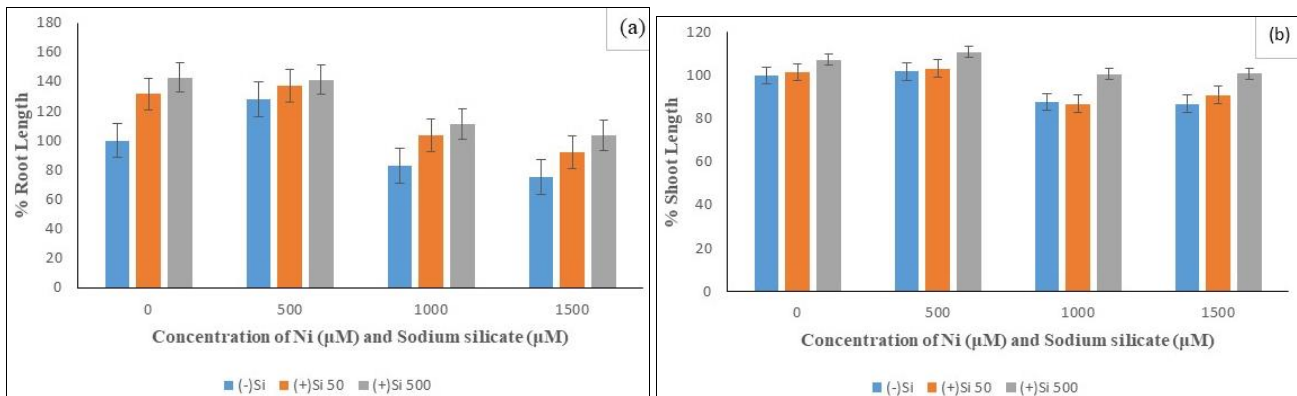
The absorbance was read at 520 nm using toluene as blank. The proline content in each sample was calculated from the standard curve.

Data presented is the mean of triplicate ( $n=3$ ). Statistical analysis was accomplished using Microsoft Excel. Results have been depicted as Mean  $\pm$  SD. The significance of data was carried out at  $P<0.05$  significance level using Microsoft Excel.

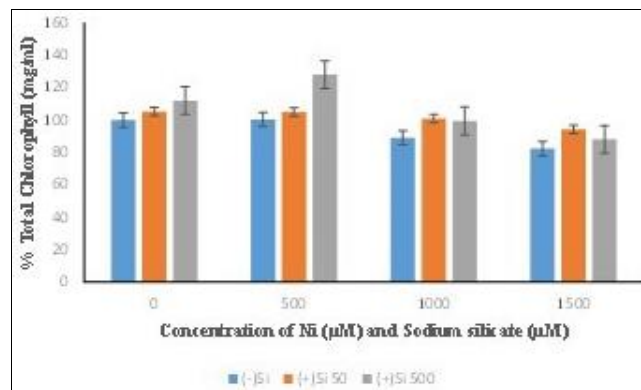
### Results

#### 1. Effect of studied doses of Ni and sodium silicate on growth parameters of *Brassica juncea* L.

Effect of different concentrations of Ni (0, 500, 1000, 1500  $\mu\text{M}$ ) and sodium silicate (50 and 500  $\mu\text{M}$ ) on growth parameters such as root length and shoot length in *Brassica juncea* L. seedlings is shown in Figure 1(a) and (b) respectively. The root length of the seedlings after 30 days of sowing (DAS) showed a declining trend with all the studied concentrations of Ni alone except at 500  $\mu\text{M}$  when a noticeable increase of 28% was observed. The recorded decline in root length for higher concentrations of Ni (1000 and 1500  $\mu\text{M}$ ) was significantly large being 17% and 25% respectively. However, in the present study, exogenous supplementation of Si (both 50 and 500  $\mu\text{M}$ ) alone and together with 500 and 1000  $\mu\text{M}$  Ni exhibited an increasing trend in root length. The highest concentration of Ni (1500  $\mu\text{M}$ ) together with 500  $\mu\text{M}$  Si also exhibited an insignificant increase in root length of 3%. The studied concentrations of Ni (0, 500, 1000, 1500  $\mu\text{M}$ ) and Si (50 and 500  $\mu\text{M}$ ) alone and in combination exhibited interesting results in shoot length of seedlings as shown in Figure 1 (b). Ni (500  $\mu\text{M}$ ) stimulated the growth of the seedlings approximately by 2% as compared to that of control. However, higher doses of Ni (1000, 1500  $\mu\text{M}$ ) exhibited a declining trend like that observed in root length. There was significant inhibition in shoot length of 12% and 13% for 1000 and 1500  $\mu\text{M}$  Ni respectively. Si alone and together with Ni exhibited slight stimulation in shoot length of seedlings except for the treatment of 50  $\mu\text{M}$  Si together with 1000 and 1500  $\mu\text{M}$  Ni. Thus, Ni at higher concentrations showed concentration dependent inhibition of shoot length and this decline was improved due to the combined treatment of Si (500  $\mu\text{M}$ ). Figure 2 depicts the graphical representation of the total chlorophyll (Chl) content. An insignificant increase in total Chl content was observed at 500  $\mu\text{M}$  Ni while a decline of 11% and 18% was recorded in this parameter at higher concentrations of Ni (1000 and 1500  $\mu\text{M}$  respectively as seen in Figure 2 as compared to control. Both the studied concentrations of Si caused significant stimulation of 5% and 12% respectively in total Chl content as compared to control. The present study showed that in combined doses of Ni and Si, 500  $\mu\text{M}$  Si exhibited better results in total Chl content in leaves of *Brassica juncea* seedlings. A similar trend of enhancement in total chlorophyll content of 5% and 28% was observed in case of combined treatment of 500 Ni  $\mu\text{M}$  together with 50  $\mu\text{M}$  and 500  $\mu\text{M}$  Si respectively. However, higher doses of Ni (1000 and 1500  $\mu\text{M}$ ) even when treated with Si (50 and 500  $\mu\text{M}$ ) caused a decline in the total chlorophyll content of the treated seedlings of *Brassica juncea* after 30 DAS.



**Fig 1:** Effect of different concentrations of nickel (0, 500, 1000 and 1500  $\mu\text{M}$ ) and sodium silicate (50 and 500  $\mu\text{M}$ ) on (a) Root length and (b) Shoot length in germinated seedlings of *Brassica juncea* L.



**Fig 2:** Effect of different concentrations of nickel (0, 500, 1000 and 1500  $\mu\text{M}$ ) and sodium silicate (50 and 500  $\mu\text{M}$ ) on total chlorophyll in germinated seedlings of *Brassica juncea* L.

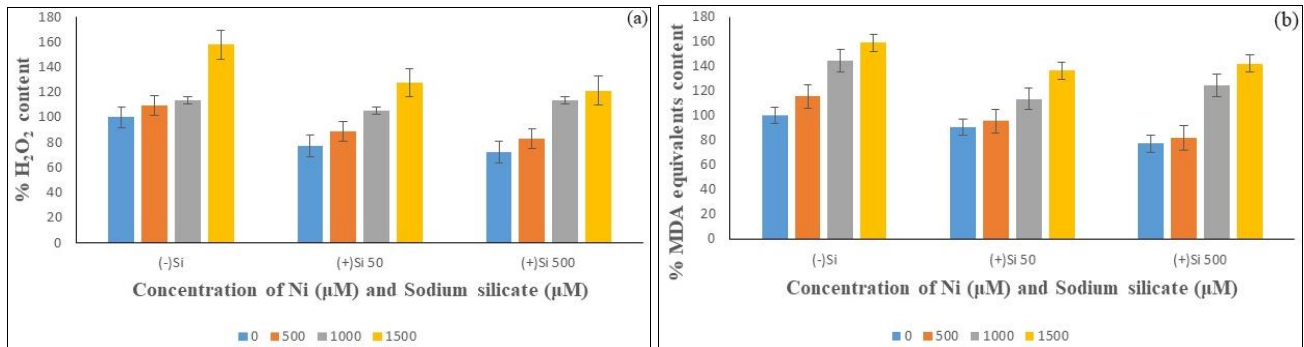
## 2. Effect of studied doses of Ni and sodium silicate on markers of oxidative stress in *Brassica juncea* L. seedlings

Figure 3 (a) and (b) show the effect of different concentrations of Ni (0, 500, 1000, 1500  $\mu\text{M}$ ) and sodium silicate (50 and 500  $\mu\text{M}$ ) on the content of hydrogen peroxide and malondialdehyde content in *Brassica juncea* L. seedlings respectively. Both the values are expressed as percentage of control. The recorded  $\text{H}_2\text{O}_2$  content was  $500.84 \text{ nmol g}^{-1} \text{ FW}$  and that of MDA equivalents was  $22 \text{ nmol g}^{-1} \text{ FW}$  in control seedlings of *Brassica juncea* respectively. Increase in Ni concentration resulted in greater generation/accumulation of  $\text{H}_2\text{O}_2$  and MDA, however, it was observed that both the doses of Si alone could alleviate the heavy metal stress considerably. Combined treatment with Ni and Si further reduced the quantity of these harmful ROS in a dose dependent manner. Supplementing with 500  $\mu\text{M}$  Si alone caused a reduction of 28% and 23% in  $\text{H}_2\text{O}_2$  and MDA content respectively as compared to control. It was observed that with combined treatment of higher doses of Ni and Si, both  $\text{H}_2\text{O}_2$  and MDA content exhibited an increasing trend with maximum increase being observed in the case of 1500  $\mu\text{M}$  Ni treatment combined with 500  $\mu\text{M}$  Si. However, it is important to note that these values were comparatively less when compared with the values observed in case of 1500  $\mu\text{M}$  Ni treatment alone.

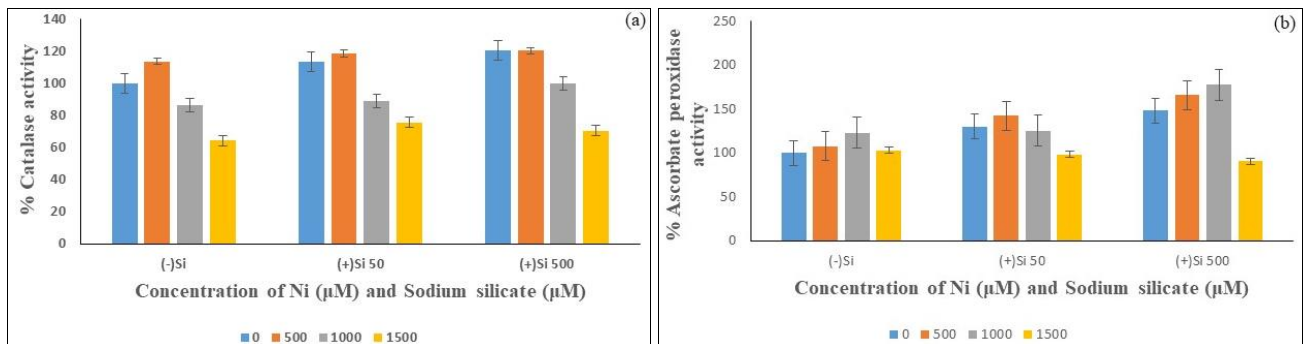
Results in Graph 4 (a) and (b) show the graphical representation of Catalase (CAT) and Ascorbate peroxidase (APX) activity (expressed as % of control) under the studied conditions. The CAT and APX activity recorded in control seedlings was  $750.76 \text{ Units g}^{-1} \text{ FW}$  and  $8470 \text{ Units g}^{-1} \text{ FW}$

respectively. Stimulation in recorded CAT activity was observed for 500  $\mu\text{M}$  Ni alone and both the studied concentrations of Si when supplemented to plants singly. Furthermore, increase in CAT activity was also recorded at 500  $\mu\text{M}$  Ni when treated together with 50 and 500  $\mu\text{M}$  Si. The higher studied concentrations of Ni recorded considerable decline in CAT activity. Declining trend continued when Ni (1000 and 1500  $\mu\text{M}$ ) was supplemented with both the studied doses of Si. APX activity exhibited an increasing trend as compared to control at all the studied concentrations of Ni and Si both, when treated alone and in combination. However, 1500  $\mu\text{M}$  Ni even in combination with both doses of Si exhibited a decline of 2% and 10% respectively in the recorded APX activity under the studied test conditions.

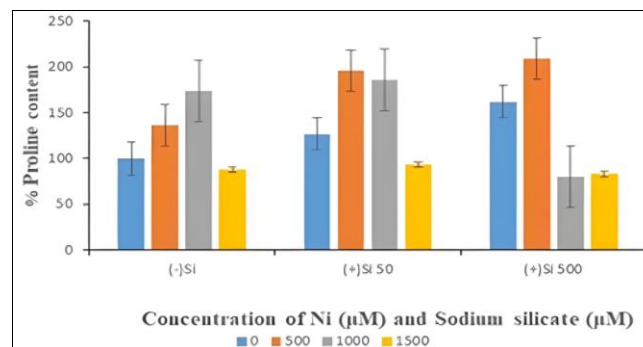
Figure 5 shows the observations for the graph of the estimated proline content in the studied seedlings of *Brassica juncea* under single and combined treatments of Ni (0  $\mu\text{M}$ , 500  $\mu\text{M}$ , 1000  $\mu\text{M}$  and 1500  $\mu\text{M}$ ) and sodium silicate (50  $\mu\text{M}$ , 500  $\mu\text{M}$ ). The proline content in control seedlings was  $250 \text{ nmol g}^{-1} \text{ FW}$ . The graph shows the recorded proline content under studied conditions expressed as percentage of control. Proline content exhibited an increasing trend in a dose dependent manner except at 1500  $\mu\text{M}$  Ni. A similar significant exacerbation in proline content was also observed in case of Si treatments alone. However, proline content in the studied seedlings showed significant decline of 7% and 17% respectively at the highest concentration of Ni even when supplemented with 50 and 500  $\mu\text{M}$  Si. An important observation was that maximum proline content was recorded at 500  $\mu\text{M}$  Ni + 500  $\mu\text{M}$  Si.



**Fig 3:** Effect of different concentrations of nickel (0, 500, 1000 and 1500 μM) and sodium silicate (50 and 500 μM) on (a) Hydrogen peroxide and (b) Malondialdehyde content in germinated seedlings of *Brassica juncea* L.



**Fig 4:** Effect of different concentrations of nickel (0, 500, 1000 and 1500 μM) and sodium silicate (50 and 500 μM) on (a) Catalase (CAT) and (b) Ascorbate peroxidase (APX) activity in germinated seedlings of *Brassica juncea* L.



**Fig 5:** Effect of different concentrations of nickel (0, 500, 1000 and 1500 μM) and sodium silicate (50 and 500 μM) on proline content in germinated seedlings of *Brassica juncea* L.

## Discussion

Induction of oxidative stress is the foremost event that precedes a heavy metal induced injury in plants. Plants harbor a number of antioxidants (both enzymatic as well as non-enzymatic) that are capable of neutralizing oxidative assaults and re-establish oxidative equilibrium. However, exposure to excessive dose of toxicants overthrows the plant homeostatic system, thus dismantling the activity of antioxidant enzymes. This anarchical situation calls for recruitment of external agents that can nullify the oxidative outburst by restoring the activity of antioxidant enzymes. Therefore, in this regard, bio-stimulants play a pivotal role since they act as damage repair agents and restore the altered homeostatic balance. The current study is an attempt to showcase biostimulatory role of sodium silicate in amelioration of nickel-induced oxidative phytotoxicity by reinstatement of antioxidant enzyme activity in *Brassica juncea*.

The results for root and shoot length show that treatment of Ni concentration of 500 μM exhibited significant

stimulatory effects in the studied growth parameters (root length, shoot length and pigment content) in *Brassica juncea* seedlings. On the contrary, higher dose of Ni proved to be phytotoxic. In addition, the growth parameters were significantly increased after the application of Si to the soil compared to the control/unstressed plants. Ni+Si treated plants (especially 500 μM sodium silicate) exhibited greater growth recovery than only Ni treated plants as compared to control. Thus, Si helped the plants recover from Ni toxicity. Similar to our observations, Ni is reported to promote growth at low concentrations (Fiala *et al.*, 2021, Goyal *et al.*, 2020, Srivastava *et al.*, 2012) [11, 12, 32] but its toxicity at higher concentrations is also widely reported (Mustafa *et al.*, 2023, Khan *et al.*, 2019a, Srivastava *et al.*, 2012) [18, 22, 32]. Si supplementation is reported to precipitate Ni in soil and reduce its uptake (Jan *et al.*, 2024) [17]. Ashraf *et al.* (2013) [4] reported that Si reduced the accumulation and transportation of Ni to aerial parts in tomato. Similarly, Idrees *et al.* (2013) [16] suggested that foliar application of Si alleviated Ni toxicity in periwinkle (*Catharanthus roseus*

L.) and decreased the harmful effects of Ni on its growth attributes (plant height, leaf area and fresh and dry biomass). Exposure to stressful situations in plants is accompanied by an upsurge in production of hydrogen peroxide as well as lipid peroxidation. In this regard, the current study shows that treatment with nickel led to increased hydrogen peroxide production as well as increased MDA levels (marker of lipid peroxidation) in a dose dependent manner, followed by a stupendous upsurge in both the levels in consecutive treatments (1000  $\mu\text{M}$  and 1500  $\mu\text{M}$ ). Researchers in earlier studies have also reported similar enhancement in hydrogen peroxide and MDA content (Kumar *et al.*, 2022, Dogru *et al.*, 2021, Abd-Allah *et al.*, 2019, Rizwan *et al.*, 2017) <sup>[1, 19, 27]</sup>. Nevertheless, in the present study Ni toxicity induced augmented levels of both these markers of oxidative stress were significantly attenuated on treatment with sodium silicate. Induction of ROS in plants leads to activation of the antioxidant enzymes, which is exactly what we observed in our study in the form of increased activity of catalase, ascorbate peroxidase and proline. The studied antioxidants (CAT, APX and proline) exhibited a trend which was observed to increase and/or decrease depending on the concentration of Ni and Si alone and in combination. This observation suggests the crucial role of the antioxidant molecules in the detoxification of ROS in living systems. A number of previous studies have also demonstrated the ability of sodium silicate and potassium silicate in restoring oxidative equilibrium in different plant species undergoing different heavy metal stresses, namely, cadmium stress in peas (Batool *et al.*, 2022) <sup>[6]</sup> and cadmium stress in wheat (Hussain *et al.*, 2019) <sup>[15]</sup>.

Proline is a crucial osmolyte molecule and its accumulation inside the plants in nickel stress has been associated with its osmoprotective function. Proline acts as a metal chelator and sequesters heavy metal toxicants, thereby, imparting heavy metal tolerance to afflicted plants (Aqeel *et al.*, 2021) <sup>[3]</sup>. Results in our study show Si induced increase in proline accumulation in plants in a dose dependent manner. Increased proline accumulation is a sign of triggering of plant defense response owing to Ni-induced oxidative stress condition. However, high doses of nickel lead to extreme phytotoxicity and completely overthrow the plant antioxidant system, making it unresponsive to the ensuing heavy metal stress. Nevertheless, sodium silicate performs a commendable job in detoxifying the nickel stress as is evident from significantly increased values of the antioxidants like CAT, APX and proline on treatment with combination of nickel and sodium silicate. Si-mediated activation of defense system, plays a vital role in managing ROS under Ni stress (Rachappanavar *et al.*, 2024) <sup>[24]</sup>. Research suggests that Si creates a reducing environment, and thus it significantly alleviates the adverse effects of Ni by lowering natural Ni levels in aerial parts of plants (Rachappanavar *et al.*, 2024) <sup>[24]</sup>. Idrees *et al.* (2013) <sup>[16]</sup> also reported that Si improved dry matter content by promoting Si-Ni precipitation in the root zone.

In the present study, we hypothesize that the ameliorative bio-stimulatory role of sodium silicate in restoring the oxidative metabolism and revamping the activity of antioxidant enzymes in nickel stressed plants may be due to the following factors-

1. Inhibition of nickel uptake by roots of *Brassica juncea* L (Sharma *et al.*, 2024) <sup>[31]</sup>.
2. Silicon compartmentalization in different organelles and prevention of Ni translocation (Abd-Allah *et al.*, 2019) <sup>[1]</sup>.
3. Chelation of nickel ions by sodium silicate, thus inhibiting their uptake (Tian *et al.*, 2023, Abd-Allah *et al.*, 2019) <sup>[1, 33]</sup>.
4. Sodium silicate mediated activation of gene expression of antioxidant enzymes in heavy metal stress in plants (Rachappanavar *et al.*, 2024) <sup>[24]</sup>
5. Sodium silicate increases soil pH, thus reducing nickel uptake by roots (Rachappanavar *et al.*, 2024, Tian *et al.*, 2023) <sup>[24, 33]</sup>.

However, in the present study, we have undertaken and studied the bio-stimulatory effect of sodium silicate in alleviation of nickel induced phytotoxicity in *Brassica juncea* seedlings at a basic and preliminary level. The role of Si in regulating Ni stress in plants warrants further research to better understanding mechanisms and to optimize Si application strategies for effective mitigation of heavy metal stress. A deeper understanding of the underlying mechanism which contributes to this effect, is under process and is being addressed as a part of the ensuing study.

Taken together, all these results showcase the ameliorative role of sodium silicate in detoxifying nickel stress in *Brassica juncea* plants, as is evident from sodium silicate mediated alleviation of nickel induced phytotoxic effects. Though not the first study of its kind, but surely an important one, our study demonstrates both the phases of nickel- its role as a micronutrient at low dose and as a phytotoxicant at high doses. Additionally, the ameliorative role of sodium silicate in neutralizing the phytotoxicity of nickel as well as in re-establishment of oxidative homeostasis, has been highlighted in the present study.

## Conclusion

Over the years, plants have evolved a simple yet effective antioxidant system comprising of a perfectly orchestrated plethora of antioxidant molecules to tackle both biotic and abiotic stresses. In a state of perfect homeostasis, the well-regulated antioxidant system sustains a vigil check in plants by maintaining the right amount of free radicals, obligatory for overall plant metabolism and development. However, exposure to different stresses leads to increase in ROS that trigger the antioxidant system, leading to increase in activity of antioxidant molecules- both enzymatic and non-enzymatic. On the contrary, exposure to a stress of higher magnitude has the potential to dismantle the plant antioxidant system, leading to diminution in antioxidant molecules. At a concentration of 500  $\mu\text{M}$ , Ni ions trigger the plant antioxidant system leading to increase in activity of several antioxidants (catalase, ascorbate peroxidase and proline). All of these antioxidants act in perfect synchronization to alleviate the stress leading to restoration of oxidative balance as observed in the form of enhanced root and shoot length and increase in photosynthetic pigments. Therefore, these findings reiterate the ability of low dose of nickel to act as a micronutrient, which boosts plant production (Yadav *et al.*, 2022) <sup>[36]</sup>. However, increasing the concentration of Ni, unleashes its phytotoxic potential and ability to obliterate the antioxidant system, as

is evident from decline in values of the above-mentioned antioxidant parameters. Additionally, biostimulatory role of sodium silicate has been re-instated in the present study. However, the highlight of the present study was the best biostimulatory effect of sodium silicate being observed at a concentration of 500  $\mu\text{M}$  at which the antioxidant molecules (both enzymatic as well as non-enzymatic) act in harmony to detoxify the harmful ROS and support the overall growth of the studied *Brassica juncea* L. seedlings.

**Declaration of competing interest:** The authors declare that there is no conflict of interest regarding the publication of this paper.

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#### Author contribution:

**AY:** Wrote the manuscript and performed experiments

**AK, GG:** Analyzed and interpreted data and also performed the experiments

**GD:** conceptualized and supervised the study

The whole manuscript was approved by all authors.

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