Effects of lithium on seed germination and plant growth indices in *Solanum lycopersicum*

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Abstract
A non-essential trace element referred to as "white gold" is lithium (Li). According to its concentration, it either promotes or inhibits plant development. The current study analyses the fresh and dried weights, morphological traits and germination of Solanum lycopersicum L. (Solanaceae) plant growth characteristics and seed germination of Li-spiked soil at five different concentrations (10ppm, 25ppm, 50ppm, 75ppm and 100ppm). The experiment yielded the following results for Li at all concentrations: Germination index (GRI), Mean daily germination (MDG), Mean germination time (MGT), Final germination percentage (FGP), Germination value (GV) and Stress tolerance index (STI). The experimental results revealed that all S. lycopersicum germination parameters were impacted by the higher concentrations of Li in the soil. The root and shoot length in S. lycopersicum decreased with increasing concentrations of Li.

Further, it was found that as Li concentrations rose, S. lycopersicum's root and shoot lengths shrank. Additionally, the stress tolerance index estimation demonstrated that lower concentrations of Li stimulated plant growth and increased biomass at higher concentrations.

Keywords: Accumulation, Germination, *Solanum lycopersicum*, Lithium, Plant growth parameters.

Introduction

Lithium (Li) is one of the elements that empower modern technology and it produces about one lakh tons per annum on average globally[15]. Its abundant availability causes many adverse effects on the ecosystem and living beings, especially plants. Overexploitation has become a serious concern as the demand for Li for electric cars and other items continues to rise and causes pollution[14]. It dramatically affects the ecosystem health through industries, mining activities, landfills, vehicles and agricultural run-offs[17] and other natural sources such as volcanic activity, corrosion of metals, geological weathering and soil erosion[23,40].

Li, which has an atomic number of three and makes up around 0.0006% of the earth's crust, is said to have the lowest density out of all the metals[47]. It is mainly used in ceramics, electric cars, mobile phones, laptops and other electronic equipment's. Additionally, it serves as a catalyst in the production of synthetic rubber and plastics[5,13,63]. The current global output of Li is projected to be around 77 thousand tons' year^{-1}, which is three times more than it was at the beginning of the millennium[60]. Australia accounts for 52% of this production, Chile for 25% and China for 13% (weforum.org).

According to an analysis, the price of imported lithium-ion cells in India increased sevenfold, from $180 million to over $1.2 billion, between 2014 and 2021. The increasing usage of Li has resulted in the metal finding its way into the biological environment. Li at lower levels is found to be beneficial for living organisms as it helps in neuro-transmission[33]. However, Li concentrations above 15-20 mg/l are highly toxic to human beings as they result in vision problems, renal disorders, nausea and even leading to death by cardiac arrest[16]. Thus, the concern for lithium toxicity has grown worldwide.

Lithium accumulation in soils mainly depends on the type of mineral, the composition of rock and soil pH. Lithium solubility is evaluated as enhanced in acidic soils[5]. The soil's physical characteristics, such as texture, permeability and bulk density, determine the dynamics of Li accumulation; clayey regions behold more Li when compared to the non-clayey regions and similarly, top soils behold less lithium than the beneath-level soils[50]. Climate conditions also affect lithium buildup, with arid regions being particularly affected. Li present in soils moves upward and may precipitate with chlorides and sulphates and in humid areas, the movement of lithium is governed more towards the deeper layers of the soil[3]. Thus, the reclamation of polluted soils has been one of the major criteria among the scientific community across the globe.

Various methodologies are being used for pollutant removal and phytoremediation has been gaining huge prominence due to its low-cost nature and high efficiency. Karri et al[38] reviewed the source, pathway of contamination and remediation of Li using plant species. Phytoremediation is using plants to either extract and eliminate elemental contaminants from soil or to reduce their bioavailability[12].

Prior to evaluating the full potential of the phytoremediation process, it is essential to look at how heavy metals affect plants when they are still seedlings. A plant's seed is a stage of life highly resistant to many environmental challenges[52]. A critical stage that is thought to be a deciding factor in crop production performance, particularly in arid and semi-arid settings, is seed germination.

As a result, knowledge of the seed germination process in harsh environmental settings[27] and heavy metal stress is essential. A related investigation on the impact of lithium ion *Amaranthus viridis* seed germination and plant growth showed that the higher soil lithium content had an impact on pertinent germination parameters[24]. The current study will conduct a seed germination experiment of a few selected plant species, specifically *S. lycopersicum*, to ascertain the germination percentage, mean daily germination, mean germination time, germination index and germination value.

It is predicted that in a developed country like USA alone, transport accounts for 28% of the total GHG emissions and in developing country like India, 14% of GHG emissions are due to energy-related CO_2 emissions[25]. The transition of energy usage from fossil fuels to clean energy has also paved the way for lithium batteries to be used extensively in electro-mobility. [59]At the global level, it has been reiterated for the G20 members that in order to boost renewable energy industry, subsidies and tax incentives must be given which will also boost the economy as well. At the same time, there has been global concern regarding the disposal of Li batteries and associated products in the environment, as soil with disposed electronic products is envisaged to accumulate lithium ions or nano particles of lithium oxide extensively[7].

The disposal of Li-containing products in landfills and open soils results in soil and groundwater contamination due to leachate forming ability; also, the physical destruction of these products may result in the release of unwanted chemicals in the natural environment[62]. The impacts of lithium on living organisms have been documented to a certain extent, as it reduces cell growth and affects the reproductive organs in human[54]. It is evident that excessive dosages (15–20 mg L-1 blood concentrations) harm the kidneys and result in unconsciousness, nausea, cardiac arrest and visual impairment. Unlike humans, animals are also affected by Li such as kidney damage etc.[48]

Lithium sharing in distinguishable properties with sodium and potassium is envisaged to interfere with the uptake of the essential elements and may result in electrochemical instability of blood transporting organs such as the atrium and ventricles[53]. There is clear evidence of the harmful effects of lithium compounds on animals since doses of 500–700 mg/kg caused nervous complications and depression in bovine animals[36]. Similarly, elevated levels of lithium-ion resulted in a reduced rate (8-27%) of respiration among soil microbes, thereby reducing the overall bacterial productivity and affecting the bio-geochemical cycles resulting in disrupting the food chains[46].

Phytoremediation of Li contaminated soils: The goal of the scientific community worldwide has been to stop lithium ions from entering the human food chain and other biological entry points which include potential strategies such as reduction of toxicity, mobility, extraction and isolation and the methods are broadly categorized into *ex situ* and *in situ*[16]. Among various methodologies to clean up polluted areas, newly emerged phyto-technological method is phytoremediation which is non-hazardous to environmental conditions with high efficacy. The fundamental principle of phytoremediation is plants' ability to remove contaminants from the soil, air, or water, lowering the pollutants' concentration[12].

Lithium is considered to be highly mobile in soil environment and by applying various amendments along with phytoremediation which is economically feasible, its toxicity can thereby be reduced drastically. Researchers[2,32,35,52] experimented on two different types of Li-containing soil with *A. venetum* and observed that germination growth was higher in LiCl than Li_2CO_3 under the same condition. *A. venetum* seeds were found to be extremely tolerant to the Li solely to the LiCl, as evidenced by the 3 to 90% germination observed in 0-150 mmol Li_2CO_3 and the 4 to 90% germination observed in 0-400 mmol L-1 LiCl. Bakhat et al[9] found that spinach responded well to a modest concentration of Li (20 mg Li kg-1), but at a larger level, pigmentation happened along with the interference of calcium and potassium uptake in plants and increased the antioxidant enzymes in the shoot. This study indicates that uptake and accumulation of Li have mostly been seen in the leaves and shoot zones which can cause health hazards to human health after consumption. In view of the potential advantages, phytoremediation is a holistic technique to remediate lithium contaminated soils. Presently, the investigation focuses on how lithium uptake is affected by seeds, seed germination, growth parameters and biomass of Li ion in commonly edible vegetable species *S.lycopersicum* (Solanaceae) and tomato is one of the top most commodities in the global food production system[56,57].

Material and Methods

Seed material preparation: The seeds of *Solanum lycopersicum* were procured from a nursery in Visakhapatnam, Andhra Pradesh and their surfaces were sterilized for five minutes in a solution of 1% sodium hypochlorite. After that, they were repeatedly and thoroughly cleaned with deionized water to get rid of any remaining disinfection solution residue[8]. For the germination test, only seeds that were complete and fully developed, were chosen. Lithium sulphate ($LiSO_4$) was used to create five concentrations of Li with increments of 25 (10, 25, 50, 75 and 100 ppm) using deionized water. The top soil consists of red soil which was sieved further. 1 gm of the soil sample from the bulk soil is characterized for Li content. After two hours of thermally acid digestion in aqua regia (HCl and HNO_3) at a 3:1 ratio, the soil sample was cooled, filtered and subjected to ICP-OES (Inductive Coupled Plasma-Optical Emission Spectroscopy) analysis for Li content. Additionally, measurements were made of the soil samples' physicochemical characteristics.

Germination experiment: The seeds of *S. lycopersicum* were equidistantly placed in Petri dishes of 9 cm dia in

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growth room. Later, soil was filled with various concentrations of lithium and in each of the Petri dishes, 40 seeds were placed. A control Petri dish was also maintained to evaluate the difference. Seeds on daily basis were treated with 10 ml of Li solution of known concentration (10, 25, 50, 75 and 100 ppm) and the germination period for study was considered to be 8 days. The germination of seeds was confirmed only if the radicle was developed up to a length of 2mm[45]. Germination was recognised when radicals emerged. The effect of Li on *S. lycopersicum* seed germination was evaluated using five potential germination indices: FGP, MDG, MGT, GI and GV.

Pot experiment: From July to September of 2024, an experiment was carried out at the greenhouse. Temperatures and humidity levels in the greenhouse were regulated to be between 20- 28º C and 50 - 84% respectively. A test was conducted to see that *Solanum*, which was grown for its bioenergy potential on Li-contaminated soil with greater concentrations, could be absorbed by heavy metals. Five Li concentrations in solution, each in three replicates make up the experiment: the control. Physicochemical properties of the soil samples are shown in table 1.

Table 1
Physico-chemical parameters of experimental soil.

Parameters	Value
pH	7.73
Conductivity	421.1 ms/cm
Exchangeable Ca	5777 mg/kg
Exchangeable Mg	2182 mg/kg
Soluble chlorides Cl_2	349.8 mg/kg
Exchangeable Na	76.01 mg/kg
Exchangeable K	101.7 mg/kg
Phosphorous as P_2O_5	137.78 Kg/Ha
Total Organic carbon	0.73 %
Copper as Cu	1.174 mg/kg
Lithium	BDL
Bulk Density	1.156 gm/cm^3

The electrical conductivity of soil was measured as 421.1 ms/cm and pH was recorded as 7.73. The total background level of Li is under BDL (below detection level). Li was added to the soil as lithium sulphate at five different concentrations: 10, 25, 50, 75 and 100 ppm Li dry soil. For the pot trails, the soil was dried and then sieved (4mm). Four kgs of earth were moved into polyethylene containers. Every plant used in these experiments is grown in a greenhouse. In a fully randomized design, a total of individual pots were used (1 cultivator, 5 treatments and 3 triplicates).

In the pot experiment, five Li amends are prepared by adding lithium and control without lithium. A total of 6 pots of 4 kg capacity were taken (five amends + control) i.e. 10 ppm, 25 ppm, 50 ppm, 75 ppm, 100ppm and control. Three replicates of each lithium amend (six), including control, were taken and 18 pots are used. Pot experiment was conducted with one vegetable – tomato and plants are grown in a greenhouse for 81 days under natural day/light conditions. After 21 days of weeding, we manually weeded the pots and irrigated them daily once, removing 10 numbers of plants per pot from 21 days to final harvesting day. The different lithium amended soils used for pot experiments were collected from final harvesting days (21, 51 and 81 days) and analysed.

Growth measurements: Following planting, the crop plants under investigation were harvested 21, 51 and 81 days later and their roots and shoots were separated. The lengths of each plants roots and shoots were noted. Furthermore, the fresh and dry weights were determined by weighing each plants constituent parts and then over drying them at 65ºC until their weight remained consistent.

Sample preparation and plant analysis: After being collected, the plants were cleaned using deionized water. From the tip of the root to the base of the shoot, the root's length was measured. The length of the shoot was measured from the base to the tip in centimeters (cm). Plants from each concentration had their root and shoots removed and dried for 24 hrs at 80ºC in a hot air oven. Shoot and root average dry weights were measured and computed independently.

Each plant's leaves were separated from the rest of the plant and dried overnight at 60 ± 1ºC in a forced air oven to a consistent weight. Each plant's leaves weighed one gram which was subsequently mashed and acid digested. All plant leaf samples were digested using a dependable, traditional digestion technique. As part of the procedure, materials were pre-digested (overnight) in a 4:1 combination of HNO_3 and H_2O_2. After further digestion, the plant material was cooked in an open vessel in the same combination at the same ratio for about 30 to 40 minutes on a hot plate. After that, a 0.45 µm syringe filter and Whatmann grade 1 filter paper were used to filter the digest. When analyzed, the filtrate's dilution factor was 1/100 since it was brought to a constant volume of 100 mL in a volumetric flask with deionized water. The OCEPS instrument was used. Li is routinely analysed by the instrument. Limit of Detection (LOD) and Limit of Quantification (LOQ) were also recorded. The equipment was recalibrated using working standards and a blank sample after every nine samples. Typical measurements made from Li blank samples were noted.

Effect of different concentrations of Li on Seed germination and seedling growth: The effect of different concentrations of Li on *Solanum* seed germination is shown in table 2. Germination test serves as primary input as to how the seeds respond to the metal toxicity[61]. Plants require several metals at minimal concentrations, which improve various processes such as biosynthesis, gene functioning, respiration, enzyme and sugar metabolism, photosynthesis and nitrogen fixation[11,58] where excess concentrations pose serious threats to the overall development of plants as reduction in growth occurs due to alteration of physiological and biochemical processes by the metals[55].

Table 2
Seed germination index of *Solanum lycopersicum* exposed to different Li concentrations.

Concentration (ppm)	Germination rate index (GRI)	Final Germination percentage (FGP)	Mean daily germination (MDG)	Mean germination time (MGT)	Germination Index (GI)	Germination Value (GV)
Control	91.9±0.38	70.0±28.3	3.50±1.41	3.93±0.62	7.65±2.58	55.1±29.49
10	80.6±13.22	46.7±4.7	2.33±0.24	3.45±0.52	5.83±0.14	30.0±2.21
25	82.9±6.32	60.0±24.5	3.0±1.22	4.11±0.79	6.18±1.67	42.4±26.09
50	69.9±2.77	83.3±12.5	4.17±0.62	3.97±0.79	9.06±1.27	82.5±20.39
75	73.2±0.99	70.0±21.6	3.50±1.08	4.20±0.67	5.87±1.05	39.1±14.74
100	64.3±8.82	80.0±8.2	4.0±0.41	4.24±0.55	8.51±1.37	32.6±17.60

Results and Discussion

***In vitro* seed germination:** Seed germination rates were higher at control at 10ppm with *S. lycopersicum* seeds (91.9% and 80.6% respectively). Lower amounts of lithium (up to 10ppm) increased seed germination rates. As Li concentration increased, GV recovery decreased significantly, with a stronger inhibitory impact. (Table 2). Lower lithium concentrations (up to 25ppm) resulted in a modest decrease in GRI. At medium concentrations (50 and 75ppm), germination rates declined to 69.9% and 73.2% respectively. Higher concentrations (100 ppm) inhibited germination by 64.3%. Pervious research on seed germination with heavy metals as Li[24], cadmium, arsenic and mercury yielded similar results[4]. In *Solanum*, under lower lithium concentrations, there was a gradual decrease in MDG. The daily germination was recorded as 3.50 in control and 2.33 in 10 ppm, 3.0 at 25 ppm, 4.17, 3.50, 4.0 at 50, 75 and 100 ppm. In the present results, lithium had insignificant impact on the MDG as the trend was irregular. Lithium did not significantly affect the average germination time of S. *lycopersicum*, as no evident impact was demonstrated. The effect of lithium on MGT was insignificant as the values ranged from 3.93, 3.45, 4.11, 3.97, 5.20 and 4.24 control, 10, 25, 50, 75 and 100 ppm respectively. The significant difference between various concentrations was very negligible possibly suggesting no correlation between lithium concentration and germination time.

The germination index (GI) in the germination assay is a very important parameter that determines how many seeds germinated in the later days of the experiment. For the seeds of *S. lycopersicum*, GI in 50 ppm induced Li-ion was highest at 9.06 and for 75 ppm, it was lowest at 5.87, thereby indicating that Li-ion had an insignificant effect on GI of *S. lycopersicum* seeds. Germination value (GV) combines both speed and final germination percentage and GV of the seeds of *S. lycopersicum* was found to be 55.1 30.0, 42.4, 82.5, 39.1 and 32.6 for control, 10, 25, 50, 75 and 100 ppm respectively.

The irregular trend indicated that Li might positively and negatively impact GV. Germination assays are very useful in assessing the deleterious effects of heavy metals on plants. As the seeds germinate, they establish the first interface medium with the surrounding environment and are highly sensitive to the environmental dynamics[64]. The mechanisms of how plants combat heavy metal toxicity remain largely unknown and the study on germination parameters thus, is of utmost importance[51].

Heavy metals have been extensively examined for their impact on seed germination, with a common technique focusing on the germination rate for certain species[49]. Green leafy vegetables are an important part of the human diet, yet they are also high in heavy metals[1,43]. Vegetables are an important part of the human diet, hence heavy metal contamination is a serious concern. Egwn et al[21] studied on *A. cruentus* growing near the vicinity of dump sites and observed that the concentrations in the vegetables exceeded the WHO/FAO permissible limits of metals used including As, Cd, Cr, Cu, Hg and Pb. Heavy metals are naturally present in the earth's crust. However, anthropogenic and industrial activities have caused significant environmental pollution. Heavy metal tolerance allows for effective approaches such as phytoremediation and bio-fortification[60].

Pot experiment to investigate the effects of Li treatments on morphological characteristics: Li treatments had a considerable impact on S. *lycopersicum's* root, shoot length and plant biomass (weight, both fresh and dried). Plant morphology is a key predictor of growth performance following exposure to heavy metals. Plant biomass can limit high levels of lithium exposure. Heavy metals can hinder plant development and growth by interfering with enzymes and biochemical activities in tissues[26].

Growth parameters: On the harvesting day of 21days, the root length was found to be decreased from 8.5 cm/plant in control and 7.4 cm/plant in 10 ppm whereas in 25 ppm it increased to 7.9 cm/plant and decreased to 6.8 cm/plant at 50 ppm. At 75 to 100 ppm, the root length decreased from 7.2 to 5.0 cm/plant by the end of 21days. The root length on harvesting day of 51days, increased from 9.7 to 15.8 cm/plant in control to 10 ppm which changed from 50 to 100 ppm (8.2 to 12.8 cm/plant). On the harvesting day of 81days, the root length increased from 13.4 to 14.9 cm/plant in control to 25 ppm, which changed from 75 to 100 ppm (15.7 to 11.0 cm/plant). The results showed that Li encouraged root growth by increasing the crop growing time (Table 3). Heavy metals may hinder plant metabolism through interactions with enzymes and biochemical reactions in plant tissues, thereby affecting plant development and growth[6].

Shoot length: At the end of 21 days, the shoot length decreased as concentrations climbed. The effect of Li concentration on the shoot length in *S. lycopersicum*, decreased from 24.2 cm for control to 14.4 cm for 100 ppm. After 51 days, shoot length grew from 22.7 to 36.7 cm/plant in the control to 25ppm group whereas it declined to 25.1 cm/plant at 50ppm. The shoot length decreased from 35.5 to 31.2 cm/plant in 75ppm to 100 ppm. After 81 days of treatment, shoot length reached 45.7cm per plant at 100ppm. Increasing concentrations and time resulted in shorter shoot lengths.

Plant length: The total plant length was 31.3 cm for control, 27.6 cm for 25 ppm decreased from control to 19.3 cm for 100 ppm in 21days. After 51 days, the plant length grew from 61.4 cm to 71.1 cm for control and 10ppm but declined from 56.9 to 50.1cm for 25 to 100ppm. With an extension in the treatment time to 81 days, the plant length was 54.1 cm at 100ppm. Thus, there is a decline in plant length with increase in concentration.

Table 3
Morphological measurements and tolerance index of *Solanum lycopersicum* grown under different Li treatments for 21, 51 and 81 days.

Day	Lithium Concentration	Control	10 ppm	25 ppm	50 ppm	75 ppm	100 ppm
21	Root Length	8.5±2.2	7.4±1.35	7.9±1.44	6.8±2.16	7.2±1.45	5±1.65
	Shoot Length	24.2±3.28	20±2.41	20±3.19	19.3±1.47	17.7±2.57	14.4±1.29
	Total Length	31.3±3.87	27.1±3.66	27.6±3.24	25.8±3.12	24.7±2.06	19.3±1.14
	Root Biomass	0.002±0.001	0.001±0.002	0.014±0.001	0.008±0.003	0.013±0.005	0.012±0.003
	Shoot Biomass	0.09±0.007	0.06±0.008	0.06±0.006	0.09±0.002	0.06±0.001	0.03±0.003
	Total Biomass	0.11±0.002	0.07±0.008	0.07±0.01	0.10±0.012	0.07±0.014	0.05±0.01
51	Root Length	9.7±2.27	15.8±1.77	14.2±4.65	8.2±3.17	12.4±2.16	12.8±2.86
	Shoot Length	22.7±6.7	35.4±6.21	36.7±5.87	25.1±1.15	35.5±4.24	31.2±2.14
	Total Length	61.4±7.12	71.1±6.04	56.9±7.26	54.6±3.33	51.8±5.16	50.1±4.05
	Root Biomass	0.1041±0.32	0.1512±0.75	0.0998±0.45	0.1680±0.35	0.0794±0.76	0.0794±0.21
	Shoot Biomass	1.106±4.23	1.107±0.224	1.615±0.71	2.050±1.87	2.130±2.28	2.381±0.45
	Total Biomass	1.96±5.45	3.04±8.57	0.41±1.24	0.68±1.92	0.84±2.76	0.44±1.43
81	Root Length	13.4±3.12	14.7±1.88	14.9±2.47	12.6±4.12	15.7±3.24	11.0±2.12
	Shoot Length	46.8±13.05	49.6±6.58	52.0±3.89	51.8±6.21	49.6±7.87	45.7±2.79
	Total Length	57.3±10.12	61.3±5.06	63.8±3.46	60.9±9.04	62.3±7.75	54.1±3.91
	Root Biomass	0.895±0.112	0.233±0.02	0.321±0.19	0.334±0.14	0.361±0.08	0.409±0.124
	Shoot Biomass	5.427±4.48	1.273±0.51	1.603±0.87	1.988±1.27	2.158±0.64	1.770±0.51
	Total Biomass	4.380±5.28	1.159±0.37	1.924±0.88	2.322±1.15	2.518±0.524	2.178±0.372

Table 4
Effect of Li concentration on the stress tolerance index of *Solanum lycopersicum* at 21, 51 and 81 days.

Day	Concentration (ppm)	*Solanum lycopersicum*			
		Root Length (cm)	Shoot Length (cm)	Root Dry Weight (gm/plant)	Shoot Dry Weight (gm/plant)
21	10	114.86	121	200	151.61
	25	107.59	121	14.28	170.91
	50	125	125.38	25	106.82
	75	118.05	136.72	15.38	151.61
	100	170	168.05	16.6	276.47
51	10	61.39	64.12	68.84	99.90
	25	68.30	61.85	104.30	68.48
	50	118.29	90.43	61.96	53.95
	75	78.22	63.94	131.10	51.92
	100	75.78	72.75	131.10	46.45
81	10	91.15	94.35	384.12	425.76
	25	89.93	90.0	278.81	338.11
	50	106.34	90.34	267.96	272.63
	75	85.35	94.35	247.92	251.15
	100	121.81	102.40	218.82	306.21

Root Biomass: Increasing Li concentrations had effect on the root biomass in *S. lycopersicum*. For control, it was 0.002 gm/plant and the effect was negligible, as the root biomass rose to 0.012 gm/plant after 21 days of treatment at 100ppm. On the harvesting day of 51 days, root biomass is 0.1041 gm/plant in control and 0.0794 gm/plant at 100 ppm. During the 81 day treatment period, the results showed that *Solanum* lithium reduced root biomass and boosted crop growth. Lithium near root tips may affect hair formation and root caps, reducing root biomass[37, 41].

Shoot Biomass: It was observed that up to 81 days, the shoot biomass dropped as concentrations increased from the control (5.427 gm/plant) to 100 ppm (1.770 gm/plant). Mulkey[42] found that greater Li concentrations resulted in decreased plant growth and chlorotic and necrotic leaves, indicating lithium stress.

Plant Biomass: The plant biomass decreased significantly at 21, 51 and 81 days. At 21 days, the total plant biomass was 0.11 gm for the control, 0.07 gm for 75 ppm and 0.05 gm for 100 ppm of lithium concentration. The same trend was observed on day 51, 1.96 gm in control and 0.44 gm in 100 ppm. For 81days, the results clearly showed that Li reduced the plant biomass with increased lithium amendment concentrations on crop growth. The primary explanation for this is a decrease in the rate of photosynthesis and nitrogen metabolism[26].

Stress Tolerance Index (STI): Stress tolerance refers to a plant's ability to live and operate normally throughout harsh conditions. Stress tolerance was determined individually for roots and shoots based on length and dry weight[4, 22]. On 21, 51 and 81 days, the stress tolerance index for root and shoot length increased from 10 to 100ppm. On day 21, stress tolerance at root length increased from 114.86 to 170 at 10 to 100 ppm. Similarly, the STI at shoot length increased from 121.0 to 168.05 at 10 to 100 ppm. On the day 51, it increased from 61.39 to 75.78 at 10 to 100 ppm where shoot length observed the increment from 64.12 to 72.75 at 10 to 100 ppm. On the day 81, the STI for root length increased from 91.15 to 121.81 at 10 to 100 ppm and shoot length increased from 94.35 to 102.40 at 10 to 100 ppm.

On 21 and 51 days, no increase in stress tolerance was seen in root or shoot dry weights ranging from 10 to 100 ppm, with the exception of root dry weight on day 81. Stress tolerance dropped from 200 to 16.6 from 10 to 100ppm on day 21 and on day 81 from 384.12 to 218.82 from 10 to 100ppm. On the other hand, after 51 days, it went from 68.84 to 131.10, up from 10 to 100. Similarly, the shoot dry weight stress tolerance increased from 10 to 100ppm on days 21, but declined on day 51 and 81 from 10 to 100ppm.

Conclusion

The present study observed that the root as well as shoot length in *S. lycopersicum* decreased with increasing concentrations of lithium. Li et al[39] demonstrated that lithium chloride had negligible effect on seed germination parameters of *Brassica carrinata* but considerably affected the root and shoot length. Lithium toxicity in plants can impede root and shoot growth, affecting nutrient intake[10]. Chaitanya et al[18] studied the effect of zinc sulphate ($ZnSO_4$) on *Momordica cymbalaria* and revealed that the increasing concentration resulted in the root formation but there was a decline of shoot growth. It has been deduced from studies that different plant species have different absorption capacities of Li although majority of them facing detrimental effects, but evidence also revealed that lithium can have several positive benefits in some halophytes[34].

Hawrylak et al[28] studied the influence of lithium on the growth of sunflower and maize plants and the result was that with increasing concentrations of lithium, new shoots and roots biomass reduced, leaf areas fell and photosynthetic pigment decreased and it was observed that dry biomass decreased and photosynthetic pigments and parameters decreased in *Apocynum venetum*[34]. It was found that STI for *S. lycopersicum*, STI of root length was highest for 100 ppm (170cm) and lowest for 10 ppm(114.86cm) and for shoot biomass, STI was highest for 100 ppm (276.47gm/plant) and lowest for 50 ppm (106.8gm/plant).

The current study evaluates the impact of lithium ions on *S. lycopersicum* which is regularly included in staple diet throughout the globe. Some plant species are sensitive to heavy metals because they lack the necessary genetic mechanisms to effectively uptake, chelate and sequester these toxic metals within their cells, disruptions in key physiological processes such as photosynthesis, respiration and nutrient uptake when exposed to high concentrations, causing stress and potential death to the plant. Some plants may lack efficient root transporters that selectively absorb essential nutrients while excluding heavy metals, leading to excessive uptake of toxic metals.

However, the seeds of *S. lycopersicum* were negligibly affected by the increasing concentrations of Li as FGP, MDG, GV and GI did not show any negative trend. The FGP was found to be higher when exposed to 100 ppm Li concentration, which might indicate that the metal might have positive impact on seed germination and thus *S. lycopersicum* can be considered as tolerant species towards its toxicity. Different plant species have varying levels of tolerance to different heavy metals depending on their evolutionary history and adaptation to specific environments which can be utilized for phytoremediation.

These tolerant plants possess specialized proteins and molecules that bind to heavy metals, preventing them from interacting with critical cellular components and effectively storing them in vacuoles. Amaranthus species can accumulate significant quantities of metals from polluted irrigation water and soil[19,40,44,63]. The results clearly observed that for 21 days growth period, the roots and shoot length of *S. lycopersicum* decreased with increasing concentrations of Li. Plant biomass of tomato was stress tolerant up to 75 ppm. The present study considered 81 day growth period. Further research would provide substantial information on the growth pattern of the above mentioned species against the increasing concentrations of Li.

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