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RESEARCH ARTICLE

Impact of heavy metals assessments on the physiological aspects of spinach plant (*Spinacia oleracea* L.)

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Abstract

This study assesses the bio-concentration of heavy metals in agricultural soils and its effect on spinach (*Spinacia oleracea* L.), which belongs to the order Caryophyllales, family Amaranthaceae, subfamily, Chenopodioideae, a hyper-accumulator plant that is important for food safety. The experiments were performed on Spinach plants by using different parameters such as root and shoot length, carbohydrate content and moisture content by treating spinach plants with different concentrations of heavy metals like cadmium, lead and arsenic. In the greenhouse experiment, the spinach seeds were sown in pots containing metal-amended soil solutions in concentrations of 0, 50,100, 150, and 200 mg kg^{-1}. According to the assessment of response to metals after eight weeks of exposure, the length parameters of both root and shoot significantly decreased with the increment of metal concentrations. Cadmium and lead were specifically identified as the most phytotoxic elements, reducing root growth by 40% and shoot growth by 30% at the highest dose studied. In terms of growth, the declines were not as significant; however, this was once more attributed to arsenic. Consequently, the carbohydrate value decreased considerably when exposed to cadmium concentration in plants, while moisture content reduced to 20% in the presence of cadmium and lead and 15% under arsenic stress conditions. According to the obtained results, heavy metal toxicity reduces spinach growth and physiological processes, including photosynthesis and water uptake, which are fatal to the health of the plants and hence food quality.

Keywords: Heavy metals, Spinach (*Spinacia oleracea* L.), Bio-concentration, Cadmium, Lead, Arsenic, Phytotoxicity.

Introduction

The major problem that is associated with the soil ecosystem particularly in agricultural soil inputs of heavy metals such as cadmium (Cd), lead (Pb) and arsenic (As) (Mwegoha & Kihampa,2010; Bakshi *et al*., 2018). These metals are derived from anthropogenic and geogenic sources, such as weathering and erosion of rocks, and discharge from industries, mining, and poor disposal of wastes (Alloway & Jackson, 1991). Since they are frequently present in the soil and even in irrigation water, these metals are dangerous to plants as they are associated with useful nutrients (Khan *et al*., 2008). Spinach (*Spinacia oleracea* L.) belongs to the order Caryophyllales, family Amaranthaceae, subfamily, Chenopodioideae is one of the most consumed vegetables in the present world and due to its high nutrient sol-associating capacity, it has been found to absorb heavy metals abundantly (Farraji *et al*., 2014; Mahmoud *et al*., 2019a).

Other macrominerals include manganese (Mn), magnesium (Mg), copper (Cu) and iron (Fe); all of which play a critical role in the health of plants because they contribute to the formation of essential parts of the plant's body and participate in most physiological processes (Akanchise *et al*., 2020). For example, manganese is used very actively in the quest to separate water molecules during photosynthesis. It is present in the center of Chlorophyll molecules and is used in photosynthesis, and copper and iron are used as enzyme co-factors and metabolic activators (Campbell & Nable, 1988; Yruela, 2005). However, this leads to a lack of these minerals or takes their amounts to a higher level,

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which brings a significant change to the condition of plant health. For instance, chlorosis appears when the plant fails to have magnesium; similarly, zinc toxicity gives the same signs and stunted growth (Rout & Das, 2009). Nevertheless, there are some metals that, in case they are present in a small proportion, are more hazardous including cadmium (Cd) and lead (Pb) (Yongsheng *et al*., 2011; Singh *et al*., 2020) As photosynthesis and respiration are inhibited and oxidative stress occurs because of cadmium, the growth rate is reduced, leaves turn yellow, and the roots rot. Similar to the above effects, lead also affects the synthesis of chlorophylls for photosynthesis, and also hinders the absorption of essential nutrients leading to poor growth and productivity (Yildirim *et al*., 2019). Contamination of As affects water and nutrient uptake induces stress, and decreases the rate of photosynthesis, leading to low yield and quality of produce (Shaibur & Kawai, 2009).

Food contamination with heavy metals is an acute problem, as it is one of the significant ways of human contact with these aggressive materials (Zheng Shun An *et al*., 2018). The worst health risk is that crops such as spinach pose serious health risks when they are contaminated, and if ingested, they can lead to ailments such as renal failure and neurological disorders (Alloway & Jackson, 1991). Therefore, it is warranted to include the part on how to deal with heavy metal pollutants and the various measures that can be used to reduce the potential of the metallic element to be a pollutant, these being among others; the methods of soil management, the processes such as soil washing and phytoremediation among others (Tomczyk *et al*., 2023). The order Caryophyllales has *S. oleracea* L. often referred to as spinach among its most famous members. This botanical order comprises several wide, green, leafy vegetables. These plants could be characterized by large surface areas of the leaves in proportion to the small body mass, relatively high growth rates and the highest ability to accumulate heavy metals from the soil and surroundings (Zakir *et al*., 2018). Due to its large leaves, fast growth, and typical dietary use in humans, *S. oleracea* has become the main focus of several studies. Scientists have been studying these plants and how they can be influenced by the presence of certain types of heavy metals. The capacity of spinaches to adsorb heavy metals is rather impressive because of the large surface area of their leaves (Yongsheng *et al*., 2011; Latif *et al*., 2018). Thirdly, owing to the high growth rate of algae, it can easily absorb and accumulate these metals, which are dangerous to the human body when ingested.

S. oleracea L. is frequently consumed in diets and as a specimen is endowed with physiologically appropriate characteristics for investigating the effects of heavy metal pollutants on leafy vegetables (Mahmoud *et al*., 2019). The scientific community has turned to this plant as a reference for evaluating the impact of the active accumulation of heavy metals and their effects on humans. This research is therefore essential in demarcating techniques for controlling the presence of heavy metals and in assuring better consumption of crops like spinach (Zhao, 2020). One alternative method involves using organic matter and biochar to sequester metals, which helps reduce their uptake by plants. This can however be done to reduce the effect of the disease on plants and hence reduce the likelihood of the disease in plants by not planting susceptible plant varieties, using the proper water, suitable fertilizers and other agricultural practices (Zhang *et al*., 2020). As a consequence, an attempt should be made to attempt to periodically assess the degree of contamination that poses a threat to soil and water (Asare & Afriyie, 2021). These are erosion, depletion of soil organic matter, and pollution and all these are the causes of heavy metals build up in the soil (Kumar *et al*., 2016). Natural soils therefore have inherent metallic concentrations, and those with extraneous human gains result in environmental and health hassles (Gebre & Debelie, 2015; Ozcan *et al*., 2016). For this reason, one must have the forms of the metals in the right proportion in the soil, as well as how and with what the metals are about or can be about. Amalgamation and liquation cause the concentration of one or many metallic elements and bring down their solubility and their toxic level in turn (Tapan Adhikari *et al*., 2005).

Materials and Methods

Experimental Design

To explore the effect of heavy metal on the growth of plants spinach planting was carried out by direct sowing of seeds on planting beds (Alia *et al*., 2015). After the germination process and the initial stages of stem and root development, the young plants were transplanted into individual pots (Chetan & Ami, 2015). These potted plants were then nurtured for one month to facilitate the growth and development of the plants that could fit into the study. During this growth period, the plants were exposed to a controlled experiment in which the substrate was spiked with heavy metals. In particular, solutions with heavy metals at the concentration of (10^{-4}) were added to the pots. The heavy metals used in the study were Cadmium (Cd), arsenic (As) and lead (Pb), ably coded as HM1, HM2 and HM3 respectively. This contamination was performed over two weeks; all the treatments were repeated thrice to provide the consistency of results (Alia *et al*., 2015). Accurate collection of plant samples was done at 14 days of heavy metal exposure. To prepare the samples, spinaches were gently uprooted from the pots in which they were grown and rigorously rinsed with running tap water to ensure that all the particles of soil were washed away. This step served to determine that the later measurements as well as the analyses captured the effects of the heavy metals, not other interferences. After the collection and subsequent washing of the plant samples, several growth characteristics were determined. This involved determining the length of the roots and stems which are key signs of plant vitality as well as growth (Chetan & Ami, 2015). The selection of spinach for this study has been based on its importance as one of the regularly consumed leafy greens and its ability to accumulate heavy metals. Given the fact that spinach has a large leaf surface area, complemented by its high rate of growth, it would be ideal for use in tracking the impacts of heavy metal contamination (Gebreyohannes & Gebrekidan, 2018; Gupta *et al.*, 2021). By employing spinach, the research was designed to make some photochemical contributions to understanding how heavy metal pollutants interfere with plant metabolism and thereby human health through the food chain.

Determination of moisture content

To determine the moisture content of a sample, start by preparing and weighing a clean, dry petri plate. Record its weight as W2. Then, measure 2 g of the sample and place it into the Petri plate. Weigh the Petri plate with the sample and record this combined weight as W1. Next, place the Petri plate with the sample into a drying oven set at 110°C (Dadali *et al.*, 2007). Allow the sample to dry for at least 2 hours. After this period, carefully remove the petri plate from the oven and let it cool to room temperature, preferably in a desiccator to prevent moisture absorption from the air. Weigh the petri plate with the dried sample and record this weight as W3 (Iheanacho & Udebuani, 2009). If the weight does not remain constant over successive weighing, return the Petri plate to the oven and continue drying until a stable weight is achieved. Once a constant weight is obtained, calculate the moisture content using the formula (Adenipekun & Oyetunji, 2010; Oyelola *et al.*, 2014).

$$\text{Moisture Content (\%)} = (W3 - W2) \times 100 / (W1 - W2)$$

Here, W2 is the mass of the empty petri plate, W3 is the mass of the petri plate with the dried sample, and W1 is the mass of the petri plate with the sample before drying. Finally, report the moisture content percentage and include any observations or deviations from the expected procedure, if applicable.

Determination of total carbohydrate

The total carbohydrate content in a sample was estimated by weighing 100 mg of the sample and placed in a boiling tube. Further, 5 mL of 2.5 N hydrochloric acid (HCl) is added to the test tube and placed in a boiling water bath for three hours to hydrolyze the carbohydrates into simpler sugars. After the hydrolysis, the solutions were cooled for an hour at laboratory temperature (Mustapha & Babura, 2009). To neutralize the mixture after cooling, solid sodium carbonate is gradually added into the mixture stirring after each addition and when the bubbles start appearing the acid has been neutralized. Additionally, the total volume of the solution was maintained at 100 mL with distilled water and then spun to separate the contents. Centrifuge the sample for 10 minutes at 10,000 rpm. After centrifugation, the supernatant was collected. From the supernatant, two samples were taken, one of 0.5 mL and another of 1-mL, for further analysis using the Bio-Analyzer.

To prepare the standard solutions for calibration, working standard solutions with different concentrations were prepared. Measuring each aliquot and the standards, decrease the volume up to 1.0 mL using distilled water. Distilled water was used as an input in the experiment. Mix 4 ml of anthrone reagent into each tube; the reagent enables the carbohydrate to produce a colored complex (De Bruyn *et al.*, 1968; Taufik & Guntarti, 2016). Placed the test tubes in a boiling water bath for 10 minutes with a view of enhancing the color reaction. Furthermore, the tubes were rapidly cooled, and the color density at 630 nm was determined in a spectrophotometer or a colorimeter. The color intensity is proportional to the carbohydrate content so the total carbohydrates in the sample can be calculated.

$$\text{Total carbohydrates contents} = (\text{mg of glucose/vol. of sample used}) \times 100$$

Results

The root lengths of treated and control plant samples were measured, revealing notable differences among the groups. The control group exhibited a root length of 4.267 cm (± 1.537) as shown in Table 1. In contrast, HM1 had a shorter root length of 3.733 cm (± 0.929), indicating a lesser growth response. Conversely, HM2 demonstrated the most significant growth, with a root length of 6.667 cm (± 1.893), suggesting a strong positive response to treatment. HM3 recorded a root length of 4.333 cm (± 0.577), slightly surpassing the control. These results indicate that the treatment applied to HM2 resulted in the most substantial root growth among the samples evaluated (Figure 1).

Table 2 presents the results of shoot length measurements for treated and control spinach samples.

The data indicates that HM1 had the highest average shoot length at 12.067 cm, which surpasses the control sample's length of 10.300 cm, suggesting a positive effect

Table 1: Root length of treated and control samples

S. No.	*Plant code*	*Root length ± SD*
1	Control	4.267 ± 1.537
2	HM1	3.733 ± 0.929
3	HM2	6.667 ± 1.893
4	HM3	4.333 ± 0.577

of this treatment on plant growth. In contrast, HM2 showed a reduced average shoot length of 9.567 cm, while HM3 had the shortest average at 7.967 cm. These results illustrate a concerning trend, as both HM2 and HM3 indicate that higher concentrations of heavy metals may negatively impact shoot development. The variability in shoot lengths among the treatments highlights the influence of heavy metal exposure on spinach growth (Figure 2), reinforcing the need for further investigation into the specific effects of these contaminants on plant health and development.

Table 3 presents data on the number of leaves for treated and control spinach samples, revealing significant insights into the effects of heavy metal exposure. HM1 demonstrated the highest average leaf count at 4.667, which is notably more significant than the control sample's average of 3.333. This increase suggests that HM1 treatment may have beneficial properties that promote leaf development, potentially enhancing the plant's ability to photosynthesize and grow.

In contrast, HM2 produced an average of 4.000 leaves, indicating a moderate response to treatment. While this is an improvement over the control, it is still less than HM1, suggesting that the effectiveness of this treatment may not be as pronounced. Meanwhile, HM3 had the lowest average leaf count at 3.000, indicating that this treatment could have detrimental effects on leaf development. The absence of leaves (0.000 SD) indicates uniformity in poor growth, potentially due to higher metal concentrations that inhibit growth processes.

The variability in standard deviations, particularly the higher values for the control (1.528) and HM2 (2.000) suggests that there was more inconsistency in leaf number among these samples (Figure 3). This variability can be attributed to factors such as individual plant responses to environmental stressors or varying degrees of metal absorption.

Table 4 provides observations on the color of leaves from treated and control spinach samples, highlighting the effects of heavy metal exposure on plant health.

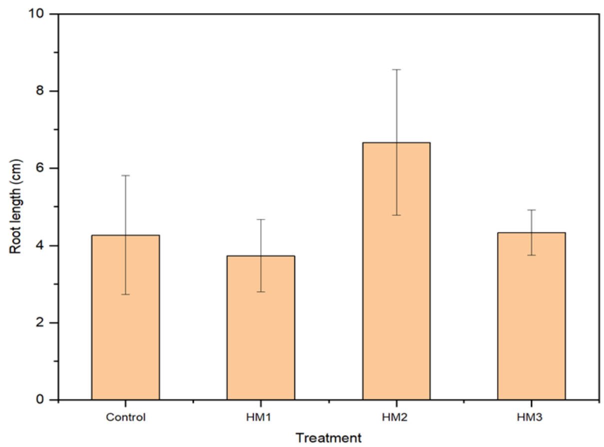

Fig.1: Effect of heavy metals on root length of Spinach plant

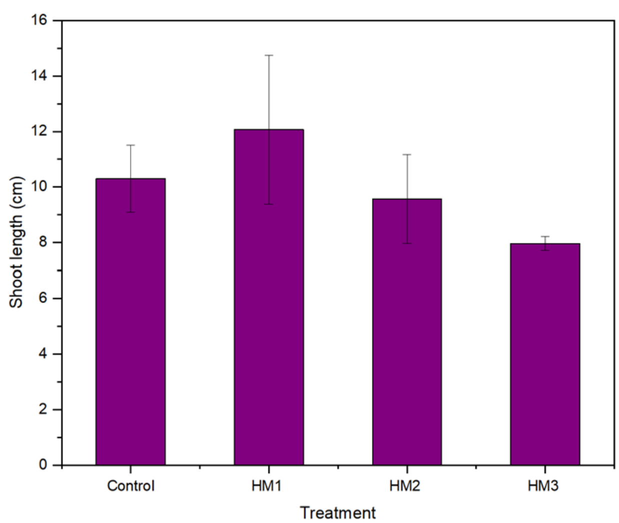

Fig.2: Effect of heavy metals on shoot length of spinach plant

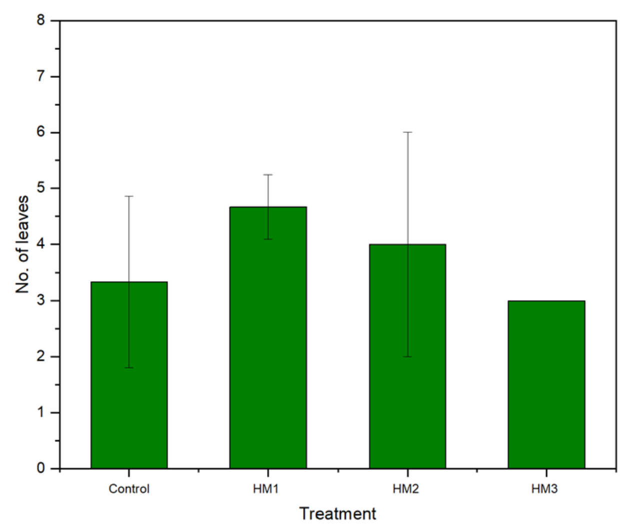

Fig.3: Effect of heavy metals on number of leaves

Table 2: Shoot length of treated and control samples

S. No.	*Plant code*	*Shoot length ± SD*
1	Control	10.300 ± 1.212
2	HM1	12.067 ± 2.686
3	HM2	9.567 ± 1.601
4	HM3	7.967 ± 0.252

Table 3: No. of leaves of treated and control samples

S. No.	*Plant code*	*No. of leaves ± SD*
1	Control	3.333 ± 1.528
2	HM1	4.667 ± 0.577
3	HM2	4.000 ± 2.000
4	HM3	3.000 ± 0.000

The leaves from the HM1 treatment show a consistent pattern of black patches, indicating potential stress or damage due to heavy metal toxicity. While one HM1 sample displays a blackish-green color, the prevalence of black patches suggests that this treatment is likely causing significant physiological stress.

In the HM2 group, all samples also exhibit black patches, reinforcing the idea that this treatment is similarly detrimental to leaf health. This uniformity in leaf discoloration suggests that HM2 may not be effective in promoting healthy growth, potentially due to high metal concentrations.

The HM3 samples present a mix of responses: two samples show black patches, while one sample is noted as green. The color variation indicates that there may be differing levels of stress among the plants in this treatment group, possibly influenced by individual plant resilience or variations in metal absorption (Figure 4).

Table 5 presents the data on the number of affected leaves for treated and control spinach samples, providing insight into the severity of heavy metal impact on plant health. The HM1 treatment shows the highest average number of affected leaves at 3.000, with a standard deviation of 1.732. This suggests significant stress or damage caused by the treatment, indicating that the heavy metals may severely impair the plant's health.

The control group has a notably lower average of 0.333 affected leaves, with a standard deviation of 0.577. This indicates that while there are some affected leaves, the control plants generally maintain better health compared to the treated samples.

HM2 shows an average of 2.333 affected leaves, with a standard deviation of 1.528 (figure 5). This result indicates a considerable negative impact, although it is less severe than HM1. The presence of affected leaves suggests that HM2 may not be effectively mitigating heavy metal stress.

HM3 has an average of 1.667 affected leaves, also with a standard deviation of 1.528. This result indicates that while there is some impact, it is less pronounced than in HM1 and HM2, suggesting that HM3 may offer some degree of resilience compared to the other treatments.

Table 6 presents the root-to-shoot ratios for treated and control spinach samples, providing insight into the relative growth of roots compared to shoots under varying conditions of heavy metal exposure.

The HM1 treatment shows the lowest root-to-shoot ratio at 0.300, with a standard deviation of 0.000. This suggests a

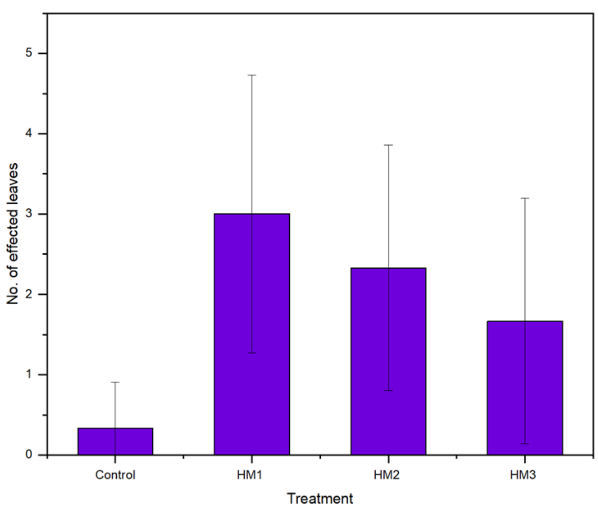

Fig.4: Effect of heavy metals on color of the leaves

Table 4: Leaves color of treated and control samples

S. No.	*Plant code*	*Color of leaves*
1	HM1 a	Black patches
2	HM1 b	Black patches
3	HM1 c	blackish green
4	HM2 a	Black patches
5	HM2 b	Black patches
6	HM2 c	Black patches
7	HM3 a	Black patches
8	HM3 b	blackish green
9	HM3 c	Green
10	Control a	Green
11	Control b	Brownish patches
12	Control c	Green

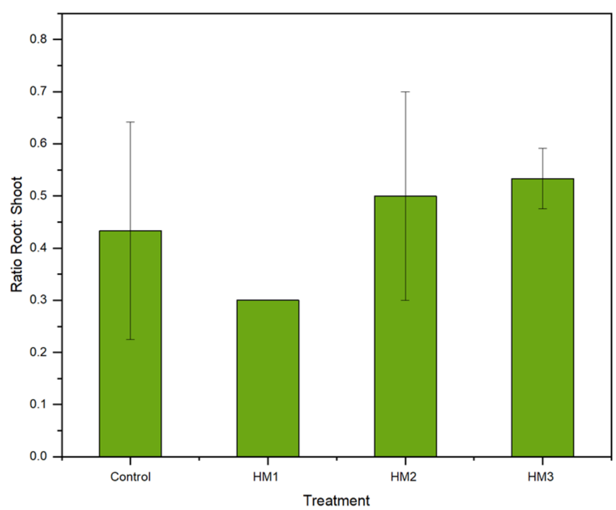

Fig.5: Effect of heavy metals on Root: Shoot ratio

Table 5: Affected leaves color of treated and control samples

S. No.	*Plant code*	*No. of affected leaves*	*SD*
1	Control	0.333	0.577
2	HM1	3.000	1.732
3	HM2	2.333	1.528
4	HM3	1.667	1.528

significant imbalance in growth, indicating that the heavy metal exposure has adversely affected root development relative to shoot growth. The lack of variability (SD = 0.000) also implies consistent results across all HM1 samples, reinforcing the severity of the impact.

In contrast, the control group exhibits a higher root-to-shoot ratio of 0.433, with a standard deviation of 0.208. This indicates healthier root and shoot development compared to HM1, suggesting that untreated plants maintain a more balanced growth pattern.

The HM2 treatment has a root-to-shoot ratio of 0.500, with a standard deviation of 0.200. This ratio indicates a moderate level of root development relative to shoot growth, suggesting that while there is some impact from heavy metals, it is not as pronounced as in HM1.

HM3 presents the highest root-to-shoot ratio at 0.533, with a low standard deviation of 0.058. This indicates a relatively balanced growth between roots and shoots, suggesting that HM3 may be the least detrimental treatment among those tested.

Table 7 presents the carbohydrate content of treated and control spinach samples, measured in mg of carbohydrates per 100 mg of leaf tissue.

The HM1 treatment shows an average carbohydrate content of 8.413 mg, with a standard deviation of 1.455. This value is relatively high, indicating that despite heavy metals, the carbohydrate levels are still maintained, although the significant standard deviation suggests variability among samples.

The control group exhibits a carbohydrate content of 8.254 mg, with a low standard deviation of 0.275. This indicates consistent carbohydrate levels across control samples, reflecting healthy leaf physiology without the stress of heavy metals.

Both HM2 and HM3 treatments show identical carbohydrate content at 8.571 mg, with standard deviations of 0.953 and 0.477, respectively. The similar carbohydrate levels in these treatments suggest that they may effectively mitigate some of the negative effects of heavy metals on carbohydrate synthesis. However, the variability in HM2 indicates less consistency among samples.

Table 8 presents the moisture content of treated and control spinach samples, expressed as a percentage (Figure 6). The control group exhibits the highest moisture content at 87.755%, with a standard deviation of 1.288. This indicates that the control plants retain a substantial amount of moisture, reflecting healthy water management and optimal growth conditions without the stress of heavy metal exposure.

In comparison, the HM1 treatment shows a significantly lower moisture content of 60.754%, with a standard deviation of 1.713. Although this value is relatively high, it suggests that the presence of heavy metals may be negatively affecting the plant's ability to retain moisture (Figure 7).

The HM2 treatment further decreases moisture content to 57.863%, with a higher standard deviation of 4.256, indicating greater variability among samples. This suggests

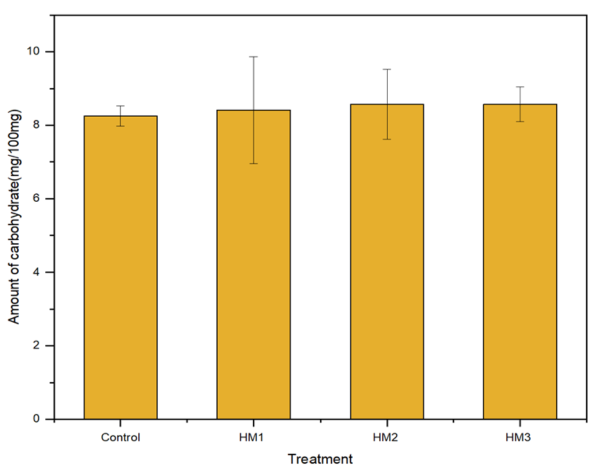

Fig. 6: Effect of heavy metals on total amount of carbohydrate

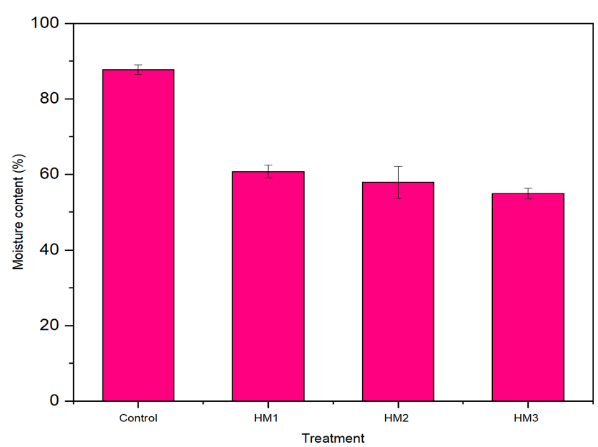

Fig.7: Effect of heavy metals on total moisture content

Table 6: Root-Shoot ratio of treated and control samples

S. No.	*Plant code*	*Ratio Root: Shoot*	*SD*
1	Control	0.433	0.208
2	HM1	0.300	0.000
3	HM2	0.500	0.200
4	HM3	0.533	0.058

Table 7: Carbohydrate content of treated and control samples

S. No.	*Plant code*	*Amount of carbohydrate (mg/100 mg)*	*SD*
1	Control	8.254	0.275
2	HM1	8.413	1.455
3	HM2	8.571	0.953
4	HM3	8.571	0.477

Table 8: Moisture content of treated and control samples

S. No.	*Plant code*	*Moisture content (%)*	*SD*
1	Control	87.755	1.288
2	HM1	60.754	1.713
3	HM2	57.863	4.256
5	HM3	54.884	1.397

that the HM2 treatment may lead to inconsistent water retention, potentially exacerbated by heavy metal stress.

HM3 has the lowest moisture content at 54.884%, with a standard deviation of 1.397. This reduction indicates that this treatment is particularly detrimental to moisture retention, which could impair overall plant health and growth.

Discussion

In the present study, the results showed that heavy metals affect spinach (*S. oleracea* L.) plants in numerous ways, which change plant root and stem growth alongside chlorophyll content and overall performance (Agbemafle *et al*., 2019). It is observed that the heavy metals have affected the plant growth on leaves, roots, shoots various other parameters like carbohydrate contents, and chlorophyll contents of plant, etc. in multiple ways. Different doses of heavy metal impacted root development either positively or negatively in our experiments. Specific treatments created shorter roots which might stop the plant from holding ground and receiving essential nutrients. Treatments that triggered root growth changes reflected both protective plant responses and growth factor stimulation according to Sethy and Ghosh's research. Root behavior reacts differently to heavy metals than shoots even though these elements have two-way effects. The measurements of shoot growth showed different outcomes among different test conditions. When substances improved shoot development some treatments led to decreased shoot growth indicating that heavy metal accumulation might interfere with plant growth. Different heavy metal treatments that boost root growth typically hinder the shoot development growth process (Sen *et al*., 2013). The way plants produce leaves shows us that heavy metals affect spinach differently. The treatments that promoted leaf development helped plants process sunlight and photosynthesis better but many other treatments failed to boost leaf creation at severe metal levels (Gill, 2014). The number of good leaves shows how well the plant deals with mental stress.

Our observations showed that different treatments stressed plant cells by changing leaf color patterns including black spots. Heavy metals appear to disrupt important plant functions that influence both the energy generation and photosynthesis physiology of the plants (Asati *et al*., 2016; Küpper *et al*., 1996). Heavy metal treatments decreased a plant's natural water absorption abilities during an evaluation of its water content. It is demonstrated that when the plants absorb heavy metals, it causes them to lose water more rapidly which limits their ability to thrive in their physiological conditions. This result is corroborated by work related to heavy metal exposure that breaks down the plant's natural water balancing system as shown by superior moisture retention in control plants (Ali & Gill, 2022). The study shows that heavy metals affect spinach growth differently depending on both metal type and treatment amount. Studying how plants manage heavy metal stress through natural defense systems will help us find ways to reduce their harm to both plants and their output.

Conclusion

This paper aims to assess the effects of heavy metal toxicity on Spinach plants (*S. oleracea* L.) about important health status parameters. Compared with the life history parameters of root and shoot lengths, leaf color, the level of carbohydrates, moisture content, and root-to-shoot ratio, many have shockingly adverse impacts that require further improvement in agricultural practices.

The observed reduced root and shoot lengths most significantly in the HM1 findings show how heavy metals inhibit primary growth and development. As one of the key processes in digesting nutrients and water such interferences affect the proper growth of roots undermining the structural support of most plant species, and their capacity to handle stress factors in their environments. Of these, the disruption of the balance between root and shoot growth has consequences for overall plant yield.

Chlorosis and other black patches resulting from physiological stress bear testimony to what heavy metals have done. These are signs of considerable damage, which points towards the need for higher measures of plant defense. An understanding of how chlorosis intensification affects the number of damaged leaves elicited how the heaviness of metal toxicity interfered with normal physiological processes like photosynthesis.

Though some treatments kept carbohydrate levels intact, the trend suggests that stress created by heavy metals hampers metabolism. Low amounts of carbohydrates have Impacted the adverse consequences on energy generation deposition and overall physiology of the crop plants. Besides this, reduced moisture content intensifies nutrient absorption issues, which would cause other issues, for example, drought stress.

Based on this data, it becomes quite apparent that there is an emerging need to come up with efficient management of such pollution in the agricultural soils. The organic supplements and the technique of phytoremediation, as well as the generation of spinach varieties having tolerance to heavy metals, are potential outcomes for increasing the tolerance degree.

This study underlines the multifaceted relationships between heavy metal toxicity and plant health and the importance of clarifying the current knowledge to improve agricultural practices. Thus, investigating such relationships becomes a prime importance as the levels of pollution rise The quality of future demands of foods and crop productivity could be affected. Therefore, it is warranted to mitigate the pollution from the contaminated environment by choosing potential crop plant through genetic engineering.

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