

Physiological and Anatomical Study of the Role of Phytoremediation of Mustard Plant in Reducing Pollutants in Najaf Governorate/Iraq

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Abstract

The experiment was conducted in Najaf Governorate/Iraq during the winter of 2023 to determine the types of some heavy metals in Najaf Governorate and to know the role of phytoremediation of mustard plant in absorbing these heavy metals and the plant's response to these pollutants by measuring some nutrients and heavy metals and studying some anatomical characteristics. Large pots were used in the experiment and distributed after a month of germination to the study sites represented by P1 – natural climate area, P2 – restaurant (Barakat Al-Sabtain Restaurant), P3 – residential neighborhood (Al-Zahraa neighborhood), P4 – airport street (Najaf Airport), and P5 – cement factory (Kufa Cement Factory). The results indicated an increase in the leaf content of elements (P, Mg, Ba, and K) in the plants found in P1, as the site recorded the highest value for these elements, which are 0.89%, 9.509 mg/Kg, 3.38 mg/Kg, and 1.44%, respectively. As for the Ca element, it was noted that its content in the plant leaves had increased in site P5, as it recorded the highest value compared to the other sites. There was a significant increase in the concentration of heavy elements (Pb, Li, and Cu) in site P5, as the site recorded the highest percentage of the mentioned elements, reaching 6.560 mg/Kg, 24.50 mg/Kg, and 15.598 mg/Kg, respectively. While a significant increase in the concentration of the elements Ni appeared in P4 and recorded the highest rates 4.342 mg/Kg, while the significant increase in Cd. It was observed in P2 and recorded the highest rate of 0.499 mg/Kg. The results of the study showed an increase in the thickness of the stem cortex, the number of its layers, and the length of the vascular bundles in plants living in environments where heavy elements increase. P5 recorded the highest value in the mentioned indicators and gave values of 44.8 mm, 8.2 mm, and 9.56 mm, while P2 recorded an increase in the number of vascular bundles and stem diameter.

Keywords: Phytoremediation, nutrients, heavy metals, anatomical traits, mustard, pollutions

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INTRODUCTION

Black mustard (*Sinapis nigra* L.) belongs to the Brassicaceae family of the Brassicales order, including more than 330 genera and more than 3,700 species that are distributed worldwide, which was previously called the Cruciferous family due to the presence of four sepals in the middle of the flower followed by four arranged petals, giving it a cruciform shape. The presence of organic sulfur compounds is also a unique and distinctive feature of this family [1]. Mustard is used externally to relieve muscular rheumatism and is also used in cases of stomach cramps, also it is a fixed oil added to the pharmaceutical ingredients needed to make the paste used to relieve pain resulting from cold snaps and exposure to low temperatures for long periods.

Popularly, mustard seeds are used in food to stimulate the digestive glands of the stomach and intestines and are used in the manufacture of mustard. Seed powder is also added to meat, fish and some foods during their processing and canning to preserve them and extend their shelf life, in addition to using seed residues as livestock feed and organic fertilizers [3]. It is grown in larger areas to obtain its seeds, The seeds contain a high percentage of fats ranging between 23% and 47%, and the most important of these fats is erucic, which reaches about 26%, in addition to other fatty acids, such as oleic, which reaches about 22% in white mustard and 19% and 22% in brown and black mustard, respectively. Linolenic acid is also found in high levels [4], However, these fatty acids are positively affected by fertilization and the nitrogen content in the soil, as well as negatively affected by the density of plants per unit area [5]. The global environment has been exposed during the second half of the last century to pollution that exceeds what it has been exposed to throughout its long history, and this has led to the emergence of new diseases and chemical and biological changes in the components of the entire biosphere, including plants, animals, and humans. Many plants and animals have been exposed to the risk of extinction. Many scientific reports have shown that there are more than 600 species of animals and birds at risk of extinction due to global environmental pollution, and that more than 1500 species of rare plants have begun to become extinct [6].

Pollution is primarily linked to the ecosystem. Environmental pollution may be defined as an effect caused by undesirable changes linked to the natural environment that have a damaging effect in all living organisms. The material that causes pollution is known as a pollutant, which may be as liquids, solids or gases. This material becomes a pollutant when its concentration surpasses its natural concentration [7]. Other indicate that this concept means the quantitative and qualitative changes that are harmful to the components of the environment, which causes it to lose its balance and thus leads to economic problems that weaken the society's ability to develop [8]. However, some of them see it as undesirable changes that surround humans, in whole or in part, due to their activity through the occurrence of direct or indirect effects that change the natural, chemical or biological components of the environment, which affects humans and the quality of life they live. Others also see it as the introduction of materials or energy into the environment by humans that are a cause of human health being exposed to risks or harm [9].

Heavy metals are a group of the most important environmental pollutants that are not subject to change and are caused by human industrial activity, such as mining, metal smelting, exhaust from internal combustion engines, oil production, dyes and their waste, agricultural applications, such as fertilizers, pesticides, sewage, waste disposal, etc. [10]. Most lead emissions, for example, over the past few decades were due to the use of gasoline [11]. However, its emissions have decreased significantly in developed countries and some developing countries due to the introduction of unleaded gasoline [12]. The increase in the concentrations of these metals in plants is due to the growth of the plant in soil or a medium polluted with these [13]. High concentrations of heavy elements may lead to negative effects on the plant, including affecting plant tissues, deformities, weak resistance to diseases, and reduced growth and productivity [14]. The problem of plant pollution is the most important environmental problem that needs a real stop to reduce it. Given the urgent need of plants for nutrition, all heavy elements are considered toxic if present in high concentrations, as they have the ability to interact with cell components and cause a disruption in their functions, whether in plants, animals, or humans [15, 16] defined pollution as a substance or effect that leads to a change in the growth rate of species in the environment, conflicts with the food chain by introducing toxins into it, or conflicts with health, comfort, or the values of society. Pollutants enter the environment into the material in noticeable quantities in the form of waste and garbage or by-products of industries or certain human activities. Pollution usually involves the dissipation of thermal and sound energy and vibrations.

Toxic metal pollution is a major environmental hazard. Chemical methods for removing heavy metal pollution, such as thermal treatment, electroremediation, soil replacement, sedimentation, and chemical leaching are generally very expensive and not applicable to agricultural lands. Therefore,

many strategies have been used to restore polluted environments. Among these methods is phytoremediation, which is a promising method based on the use of highly accumulating plant species that can tolerate large amounts of toxic substances present in the environment [17].

Heavy metals are a group of metallic chemical elements that have relatively high densities, atomic weights, and atomic numbers. Common heavy metals/metals include cadmium (Cd), mercury (Hg), lead (Pb), arsenic (As), zinc (Zn), copper (Cu), nickel (Ni), and chromium (Cr) [18]. Heavy metals are classified as essential and nonessential. Essential heavy metals are those that organisms need in small amounts to perform physiological and biochemical functions. Examples include iron, manganese, copper, zinc, and nickel. Although they are heavy elements, they are indispensable to plants at small concentrations, their accumulation at higher levels can become highly toxic to the environment [19]. The accumulation of large amounts of heavy elements causes the activation of enzymes that cause oxidative stress and malfunction in the function of chlorophyll, and thus a decrease in plant growth and photosynthesis efficiency occurs, which are the most important symptoms causing poisoning with these heavy elements [20]. Phytoremediation is defined as a green strategy that uses highly accumulating plants and atmospheric microorganisms to fix, transport, or decompose pollutants in soil, water, and the environment [21]. The success of this method depends on the availability of endemic plant species that can tolerate and accumulate high concentrations of heavy elements, as some plants can accumulate significant levels of heavy elements equal to 100–1000 weak levels in species that normally grow under the same conditions [22]. One of the most important characteristics of ideal plants prepared for phytoremediation is that they have a high capacity to absorb pollutants and tolerate their toxicity, with their simplicity in cultivation and ease of obtaining ideal vegetative and root growth for absorption with the addition of chemicals and fertilizers that enhance plant growth and development for the purpose of better performance of phytoremediation, and that these plants are not attractive to animals so that they do not cause harm to these plants when eaten [23]. Plants absorb heavy elements from their root system by two mechanisms: the first is through the apoplast and the other is through the symplast. Several transmembrane protein transporters have also been identified that participate in the balance of these elements in the plasma membrane, such as proteins associated with natural resistance-associated T., cation exchangers, cation diffusion facilitators, and ATP-binding cassettes [24]. The use of plants in the treatment of pollutants depends mainly on the resistance of plants to pollutants, which means the ability of plants to accumulate high concentrations of toxic substances in their tissues without affecting their life cycle in how plants resist the toxic and harmful effects of pollutants [25]. Plants (black eggplant, mustard, corn, lettuce, alpine grass, tobacco, sunflower, and beans) are among the most suitable plant species to be used in the process of phytoremediation [26]. Phytoremediation involves the uptake of toxic metals, translocation of the absorbed metals to the shoots and their deposition in the vacuole, cell wall, cell membrane, etc. It has been observed from some studies that some elements enhance different phytoremediation, such as Ni, Zn, Fe, B, Cr. Phytoremediation technology uses mechanisms, such as phytoextraction, phytostabilization, root filtration, phytovolatilization, phytodegradation, and phytodesalination of water. However, plants vary in their remedial capacity depending on the target pollutants. Pollutants and site conditions are crucial [27].

From the above, we set the following objectives: Study and knowledge of heavy elements and pollutants in different areas of Najaf Governorate, the role of phytoremediation of mustard plant in reducing pollutants and the effect of pollutants on the internal tissues and internal anatomy of mustard plants.

MATERIALS AND METHODS

Experimental Location and Seed Planting

Black mustard was grown from seeds purchased from agricultural offices in Najaf at the beginning of the winter season on 11/1/2023. It was added to large pots, each pot length (50 cm) and width (30 cm), in which sandy soil was placed with an amount of peat moss to improve the growth of seedlings at a rate of 1 Kg of peat moss per pot. The seeds were planted at a rate of one gram per anvil due to

the small size of the seeds and the inability to plant them individually and at a depth of 1 cm in the soil. The seeds were watered twice a week for a month until they were distributed to the sites under study.

The experiment was conducted in five different locations in Najaf to determine the effect of heavy elements and the role of phytoremediation of mustard plant in reducing these pollutants. The distribution of locations was as follows. The data were collected from the locations after about 3 months:

- *P1*: Natural climate area.
- *P2*: Restaurant (Barakat Al-Sabtain Restaurant).
- *P3*: Residential neighborhood (Al-Zahraa neighborhood).
- *P4*: Airport Street (Najaf airport).
- *P5*: Cement Factory (Kufa Cement Factory).

STUDYING INDICATORS

Nutrients

Estimation of Leaf Potassium Content (%)

The analysis was carried out using a flame photometer as described in Ahanger et al. (2013). An amount of 0.5 g of dried plant material was taken in a conical flask and digested in a ternary acid mixture ($\text{H}_2\text{SO}_4 + \text{HNO}_3 + \text{HClO}_4$ in a ratio of 9:3:1). The colorless digested material was filtered through Whatman filter paper into a 100 ml volumetric flask to make a total volume of 25 ml. About 5 ml was then taken and made up to 25 ml with distilled water and read directly on a digital flame photometer, using K filters separately and the percentage of K was determined using standard solutions.

Determination of Leaf Calcium Content

This was done according to the method of Berry and Jonson (1966). After taking 1 gram of dry matter, it was placed in digestion tubes and added 20 ml of concentrated nitric acid (HNO_3). The mixture was then gradually heated until colored vapors appeared. Heating continued until the vapors disappeared. The solution was then cooled and 5 ml of perchloric acid (HClO_4) was added, along with 25 ml of distilled water. The mixture was then filtered, and the distilled water was added to 100 ml. Calcium was then determined using an Atomic Absorption Spectrophotometer manufactured by the German company Jenway at wavelengths of 766.4- and 422.6-nm. Standard solutions for calcium was read. Dilutions of 5, 10, 15, 20, and 25 ppm were then prepared to draw a calibration curve. The readings obtained from the different samples were then extrapolated to determine the concentration.

Determination of Leaf Magnesium Content (%)

Measured by titration with ethylene diamine tetrachloride (EDTA) (Richards, 1964) using the acetic acid disodium (2Na-EDTA) method.

Estimation of the Phosphorus Content of Leaves (%)

Estimated according to the method of Olsen and Sommers (1982) where 10 ml of the digested sample solution was taken from each replicate and diluted in 40 ml of distilled water, then 10 ml of the solution was taken and 0.1 g of ascorbic acid and 4 ml of ammonium molybdate solution were added to it and the volume was completed in a flask to 100 ml with distilled water and heated in a conical flask on a hot plate for one minute until the solution turned blue, then it was transferred to a 100 ml flask and the volume was completed with distilled water. The light absorption reading of the solutions was taken by a spectrophotometer at a wavelength of 620 nm and the readings fell on the standard curve for phosphorus, then the percentage of phosphorus was calculated.

HEAVY ELEMENTS

Estimation of the Cadmium and Lead Content of Leaves

The heavy elements of plants were estimated by the wet incineration method, where 2 g of plant samples were taken after grinding them and placed in a Kjeldahl flask, then 15 ml of concentrated

nitric acid was added and heated in the digestion device until boiling for 15 minutes, then 10 ml of concentrated sulfuric acid was added to the contents of the flask, then heated until the contents of the flask turned black. Around 10 ml of concentrated nitric acid was added and heating continued until the brown nitrogen oxides were eliminated. Heating continued until the rise of these vapors stopped and the color of the sample turned into a clear and pure solution. An amount of 5 ml concentrated nitric acid was added and heating continued until the rise of white vapor stopped. The sample was left to cool, then transferred to a standard flask with a capacity of 50 ml, then the volume was completed to the mark with a diluted nitric solution of 1.5%. After that, the sample became ready for measurement. The required elements were estimated to be using a spectrophotometer. Atomic (Spectro photo-meter NOVA, A400 absorption Atomic).

Estimation of the Nickel Content of the Leaves

The weight of the dry matter of the plant under study was found and after it was placed in an electric oven for 24 hours, 0.5 g was taken from each sample after drying it at a temperature of 70°C and grinding it and digesting it by wet digestion method using sulfuric acid and hydrogen peroxide and the nickel element was estimated in the acidic extract of the dry leaves by means of the atomic absorption device according to the method mentioned by Mark et al. (2022) [28].

Determination of Copper Content in Leaves

To analyze the copper content in leaves, dried plant samples were weighed and digested using the microwave digestion method based on nitric acid according to the method mentioned in Chiou et al. (2019). An amount of 100 mg of dried samples were transferred to a Teflon vessel (capacity 55 cm³) and digested using 5 cm³ of HNO₃ (65% nitric acid) and 2 cm³ of H₂O₂ (30% hydrogen peroxide). The volume of the digested solution was adjusted to 20 cm³ using deionized water, followed by filtration using a 0.45 μm membrane filter. The prepared solution was then read by a spectrophotometer.

Preparing Cross-Sections of Mustard Plant Stems in the Laboratory

The stems of each site were collected in plastic containers containing 70% ethanol to preserve the stems after a month in their distribution sites. To make cross-sections of the stems of each site, the used stem was cut using sharp razors into small, transparent slices. After cutting these stems into slices, these slices were soaked in bleach for 10–15 minutes to rid these slices of impurities and chlorophyll pigment. After that, the slices were placed in water for a period of 10–15 minutes to get rid of the bleach substance or solution in them. Then, we put them on a slide or glass slide and placed red safranin dye on them for 5 minutes until they were well stained with the dye. After that, drops of water were placed on the glass slide to wash the slices of the plant stems from the dye and to avoid the dye clumping when examining the slide under the microscope. In this way, cross sections of the mustard plant stem were made for each site where the plant was distributed to observe the changes that occurred in the cross sections in each site and the effect of environmental pollutants on this plant (Figure 1). The following indicators were studied:

1. *Stem diameter*: It was measured with an objective lens (×4) and was not measured with Verne due to its small size.
2. *Cortex thickness*: It was measured with an objective lens (×4) from the end of the epidermis layer to the beginning of the vascular bundle and was measured for three plants and then the average was extracted.
3. *Cortex layers*: It was measured with an objective lens (×4). The number of layers of the cortex after the epidermis was calculated to the vascular bundle cap fibers (the beginning of the vascular bundle).
4. *Vascular bundle length*: It was measured with an objective lens (×10) from the end of the phloem to the end of the last xylem vessels and the lengths of the largest vascular bundles were measured and then the average was taken for three plants.
5. *Vascular bundle width*: It was measured with an objective lens (×10) from the first xylary vessel on the right of the vascular bundle to the last xylary vessel on the left.

6. *Number of vascular bundles*: All vascular bundles were calculated in the cross section of three plants and then the average was extracted.

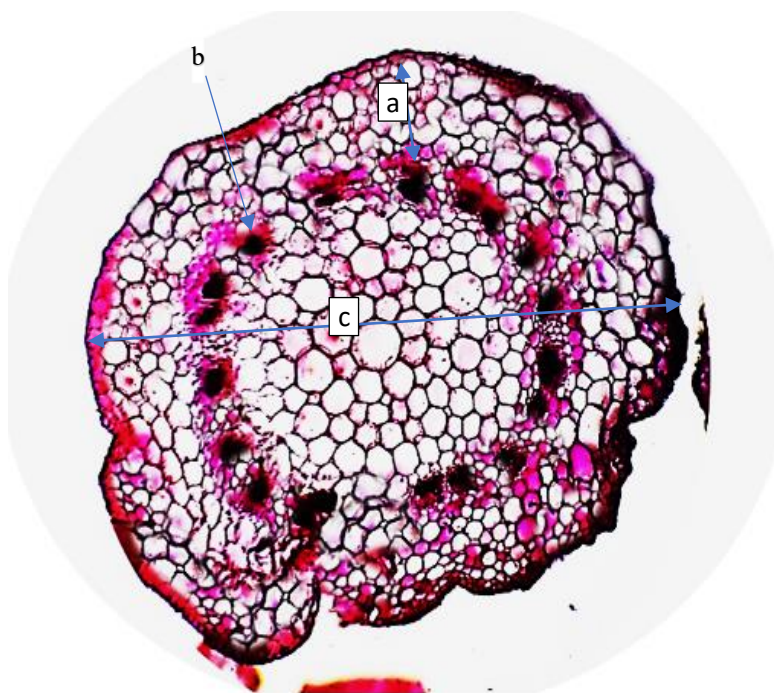


Figure 1. Internal anatomy of mustard plant stem. (Using 4× objective lens): (a) Cortex, (b) Vascular bundle, (c) Stem diameter.

RESULTS

The Effect of the Study Site on the Content of Mineral Nutrients in Mustard Leaves

The results shown in Figures 2–6 indicate the absence of significant differences in the content of mustard leaves of nutrients (Ba, Ca, K, P) for plants grown in the sites under study, regardless of their environments, which may suggest that the presence or absence of heavy elements in the external environment of these plants and the mechanism of plant processing of heavy elements and their absorption did not negatively affect the absorption of nutrients necessary for plant growth, with a significant difference in the content of leaves of Mg only. Site P3 (residential neighborhood) excelled to give the highest value of 9.05 mg/Kg compared to P1, which gave the lowest value of 0.86 mg/Kg. Site P1 (natural climate area) recorded the highest values in the content of leaves of nutrients (Ba, K, P) which are 3.38 mg/Kg, 0.89%, and 1.44%, respectively. While site P5 recorded the highest content of mustard leaves of Ca, which was 1.69 mg/Kg.

The Effect of the Study Site on the Content of Heavy Elements in Mustard Leaves

The results in Figures 7–11 indicate that the difference in the study site and the cleanliness of the environment surrounding the plants have a significant effect on the content of heavy elements in mustard leaves, and that the content of these elements in the leaves increases with the increase of pollutants in the environment of the sites under study. The results of the study showed a significant increase in the content of the elements (Ni, Pb, Cu, Li) in the site P5 (cement factory) to record the highest values of (40.86, 6.560, 15.598, 24.21) mg/Kg, respectively, compared to the other sites, while the concentration of cadmium in the leaves of the plants of site P2 (the grafted) increased to record the highest value of 0.499 mg/Kg compared to the plants of site P3, in which this element did not appear, to record the lowest value of zero. The levels of heavy elements in the different environments varied between increase and decrease according to the purity of the surrounding air and the percentage of pollutants in it.

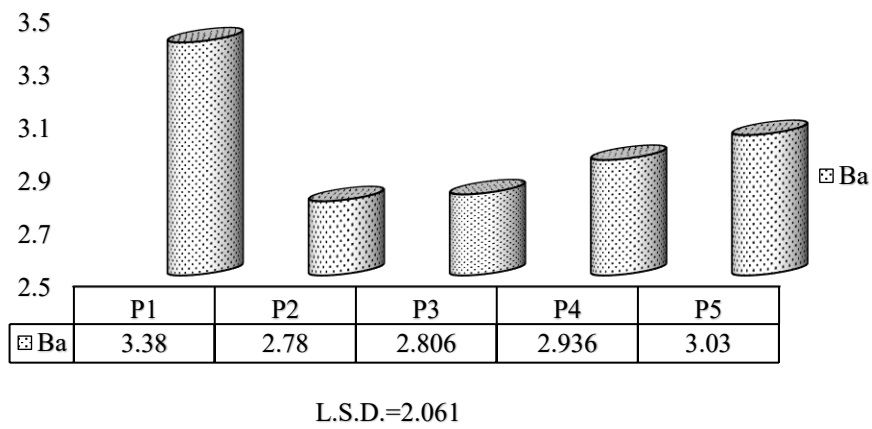


Figure 2. Effect of the study site on the leaves content of Ba.

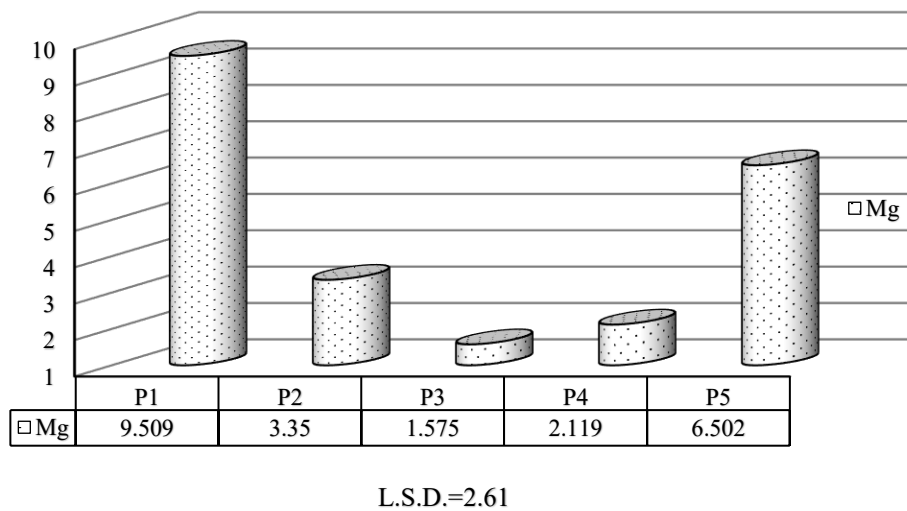


Figure 3. Effect of the study site on the leaves content of Mg.

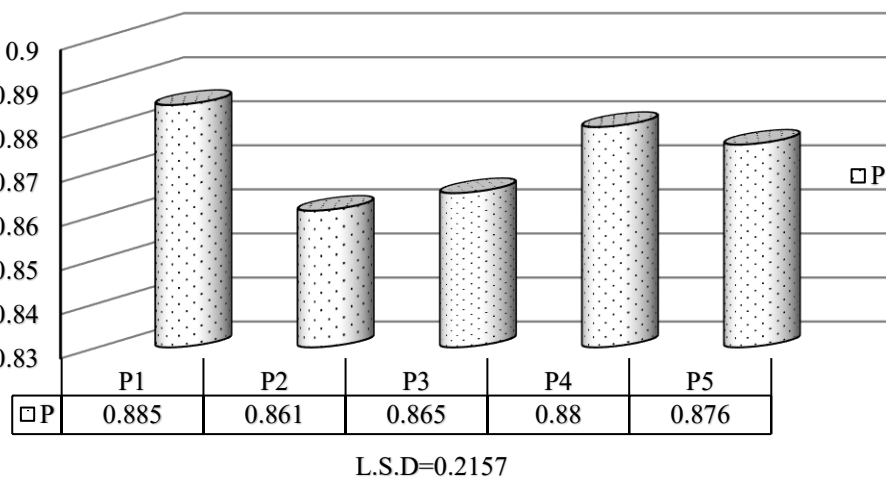


Figure 4. Effect of the study site on the leaves content of P.

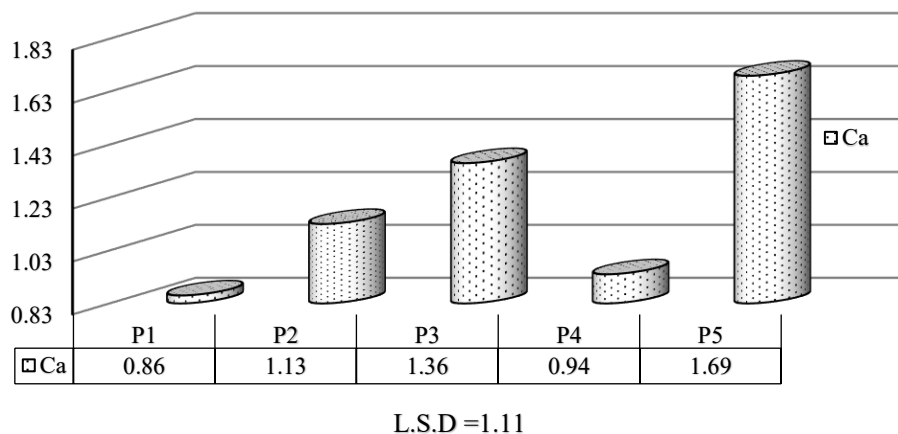


Figure 5. Effect of the study site in the leaves content of Ca.

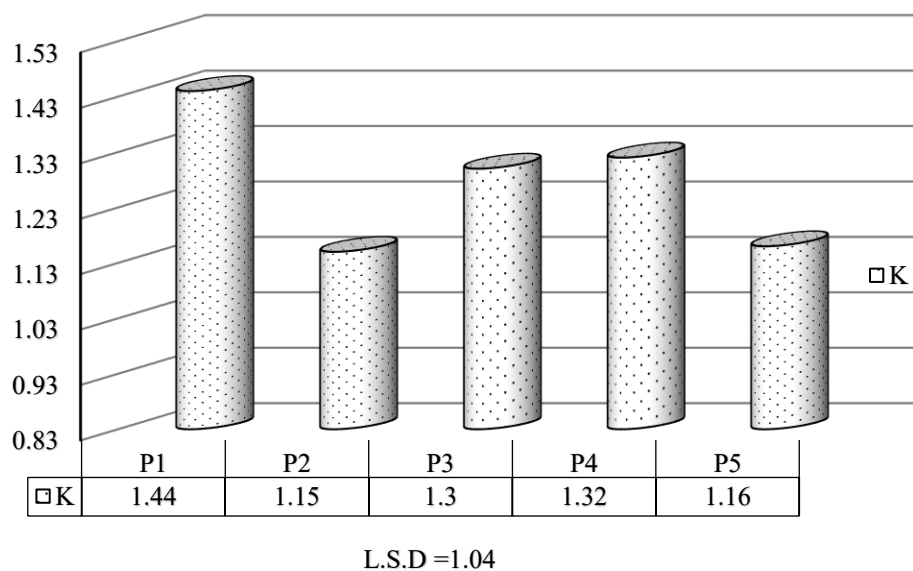


Figure 6. Effect of the study site in the leaves content of K.

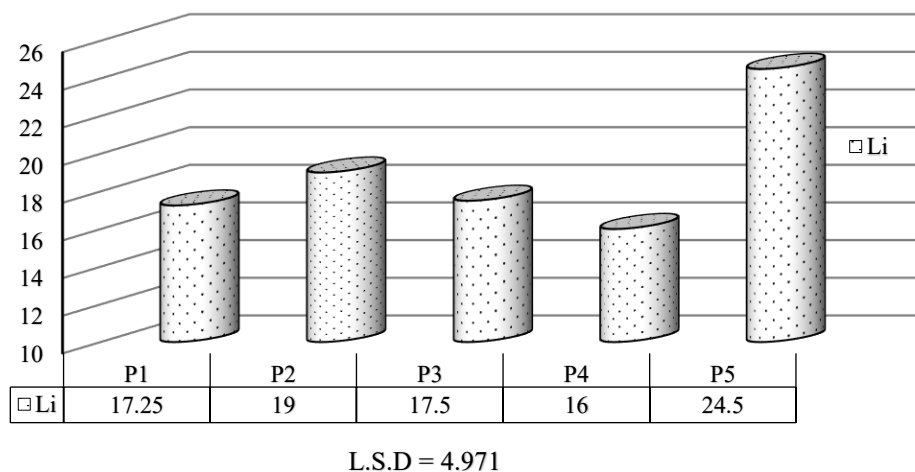


Figure 7. Effect of the study site in the leaves content of Li.

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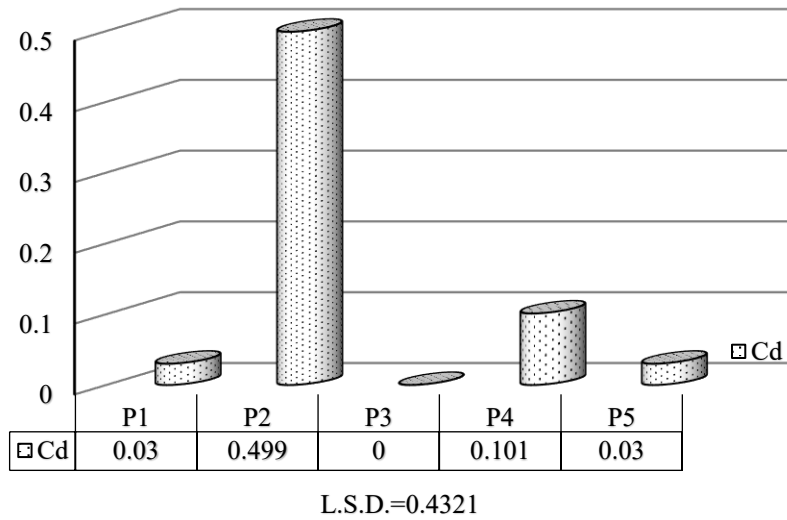


Figure 8. Effect of the study site on the leaves content of Cd.

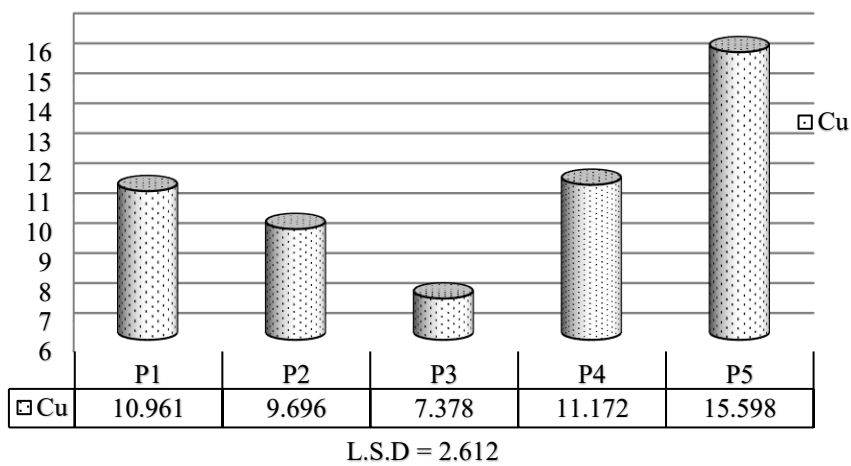


Figure 9. Effect of the study site in the leaves content of Cu.

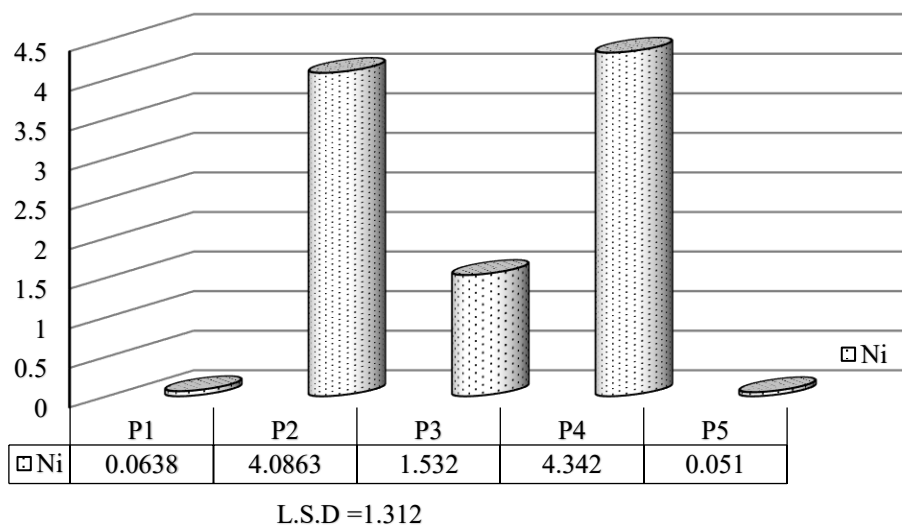
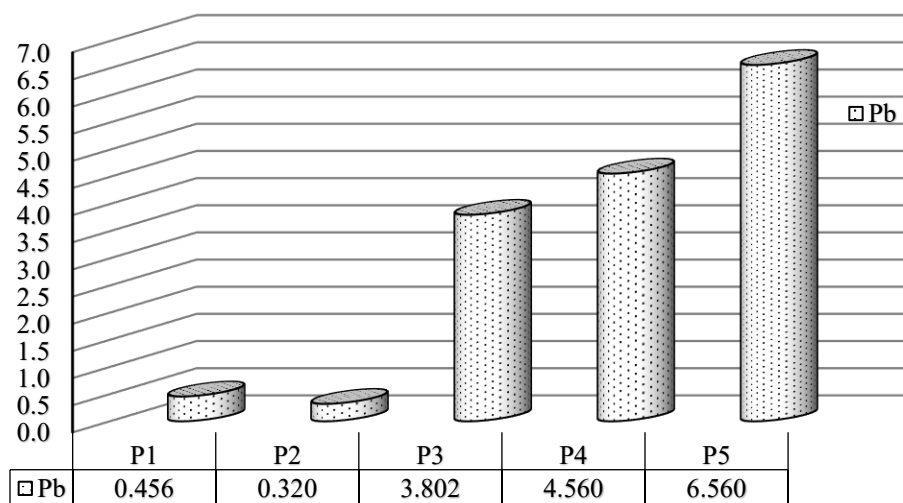


Figure 10. Effect of the study site in the leaves content of Ni.

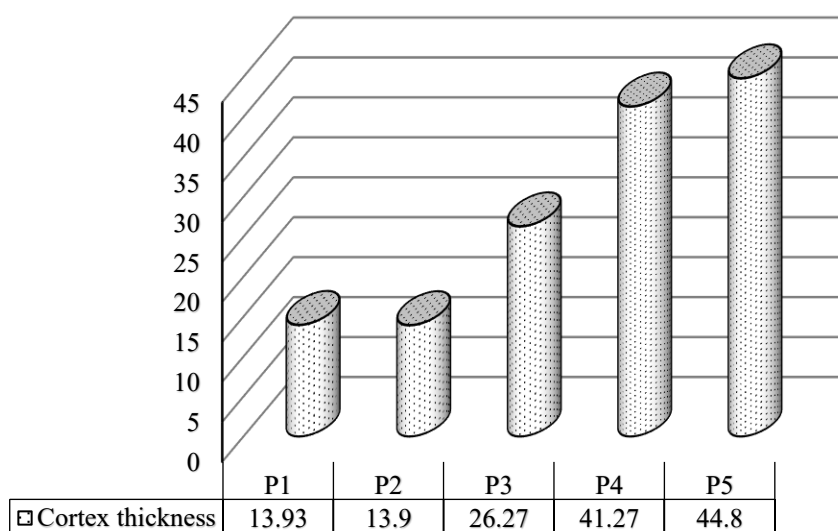


L.S.D = 1.785

Figure 11. Effect of the study site in the leaves content of Pb.

The Effect of the Study Site on the Anatomical Characteristics of the Mustard Plant Stem
The Effect of the Heavy Metals in the Anatomical Traits of Mustard Stem

The results of the Figures 11–18 generally showed the effect of pollutants on the internal anatomy of the stem, and that the increase in cortex thickness was accompanied by a reduction in the number of vascular bundles and a reduction in bundle length. The increase in heavy elements at the cement factory site was accompanied by an increase in stem cortex thickness. The results of the same figures showed a significant increase in the thickness of the mustard stem cortex at the fifth site (for plants at the Cement Factory), recording the highest average of 44.800 micrometers, compared to P1 (natural climate area), which recorded the lowest average stem cortex thickness of 13.900 micrometers. The results of the same table show a significant superiority of the restaurant site in the number of vascular bundles, recording the highest value of 20.343.



L.S.D =4.119

Figure 12. Effect of the study site in the stem cortex thickness.

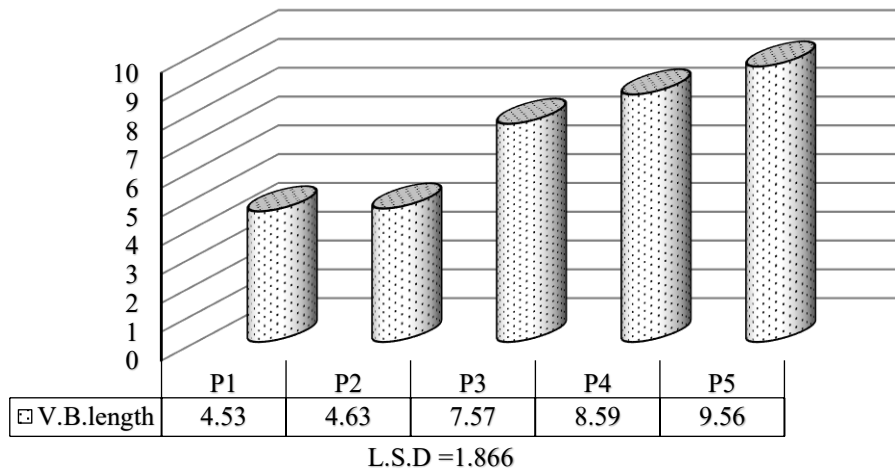


Figure 13. Effect of the study site in the vascular bundles' length of stem.

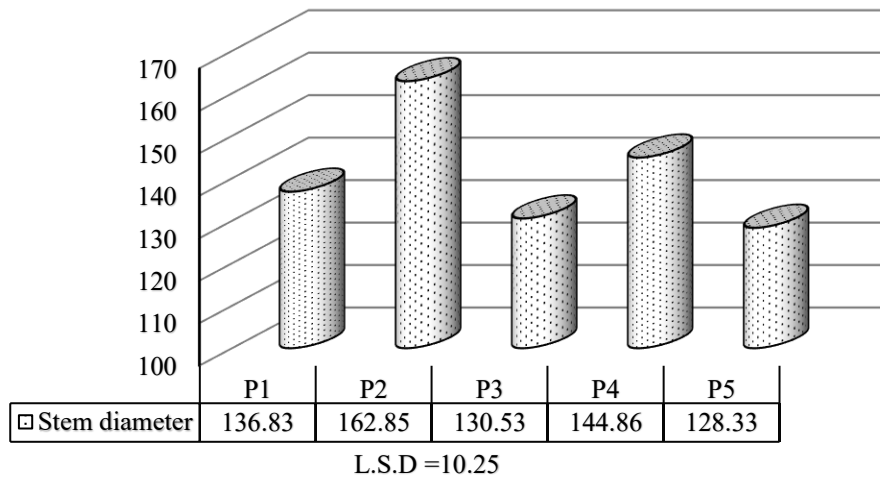


Figure 14. Effect of the study site in the stem diameter.

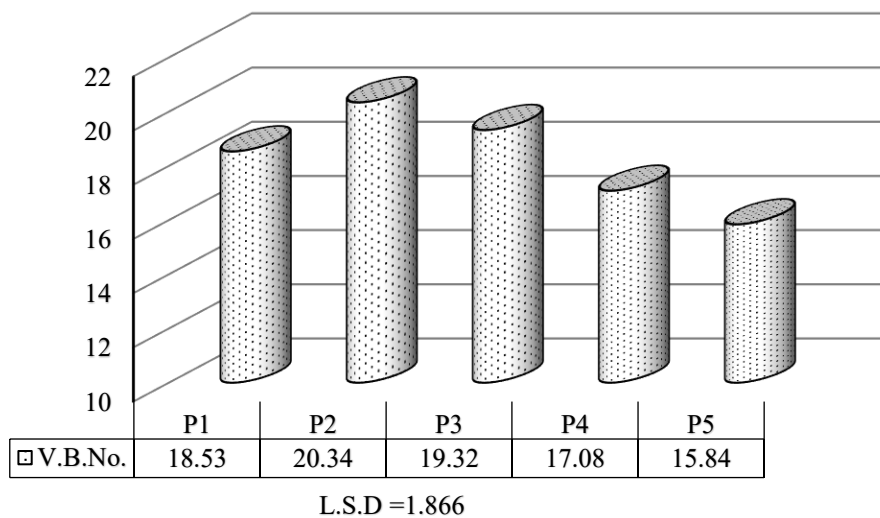
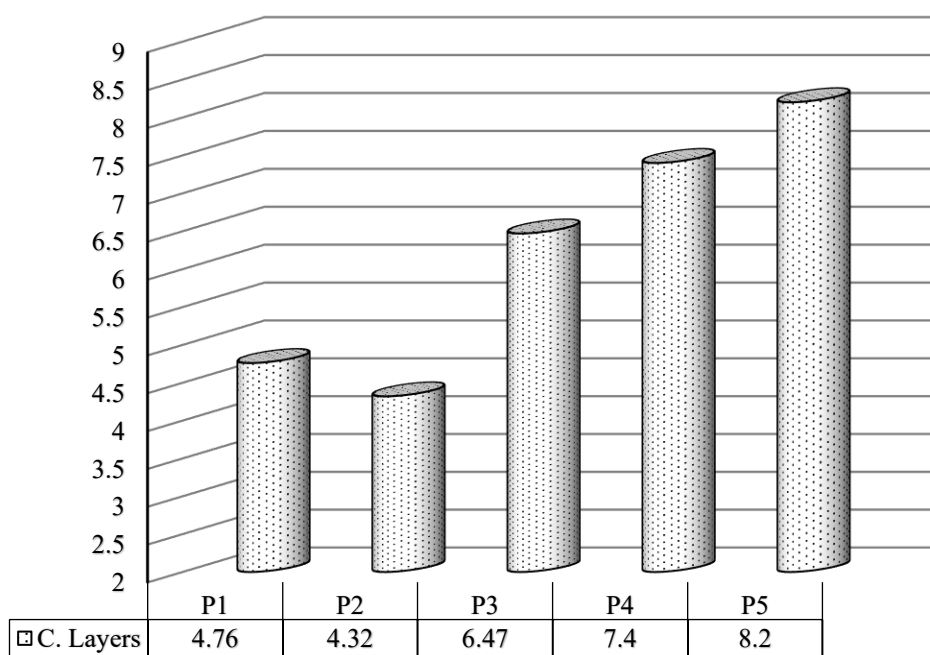
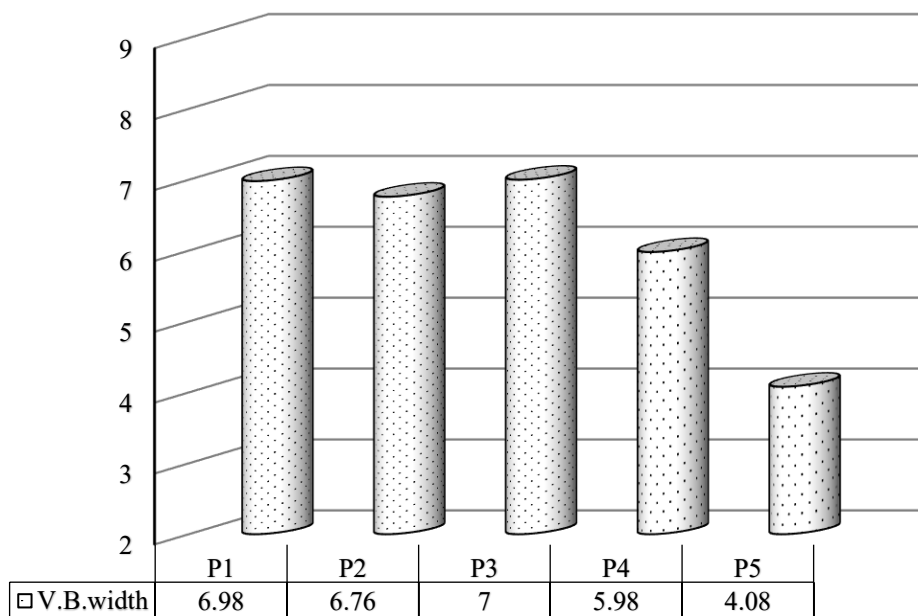


Figure 15. Effect of the study site on the vascular bundles' numbers of stem.



L.S.D = 1.729

Figure 16. Effect of the study site in the cortex layers of stem.



L.S.D = 2.114

Figure 17. Effect of the study site on the vascular bundles' width of stem.

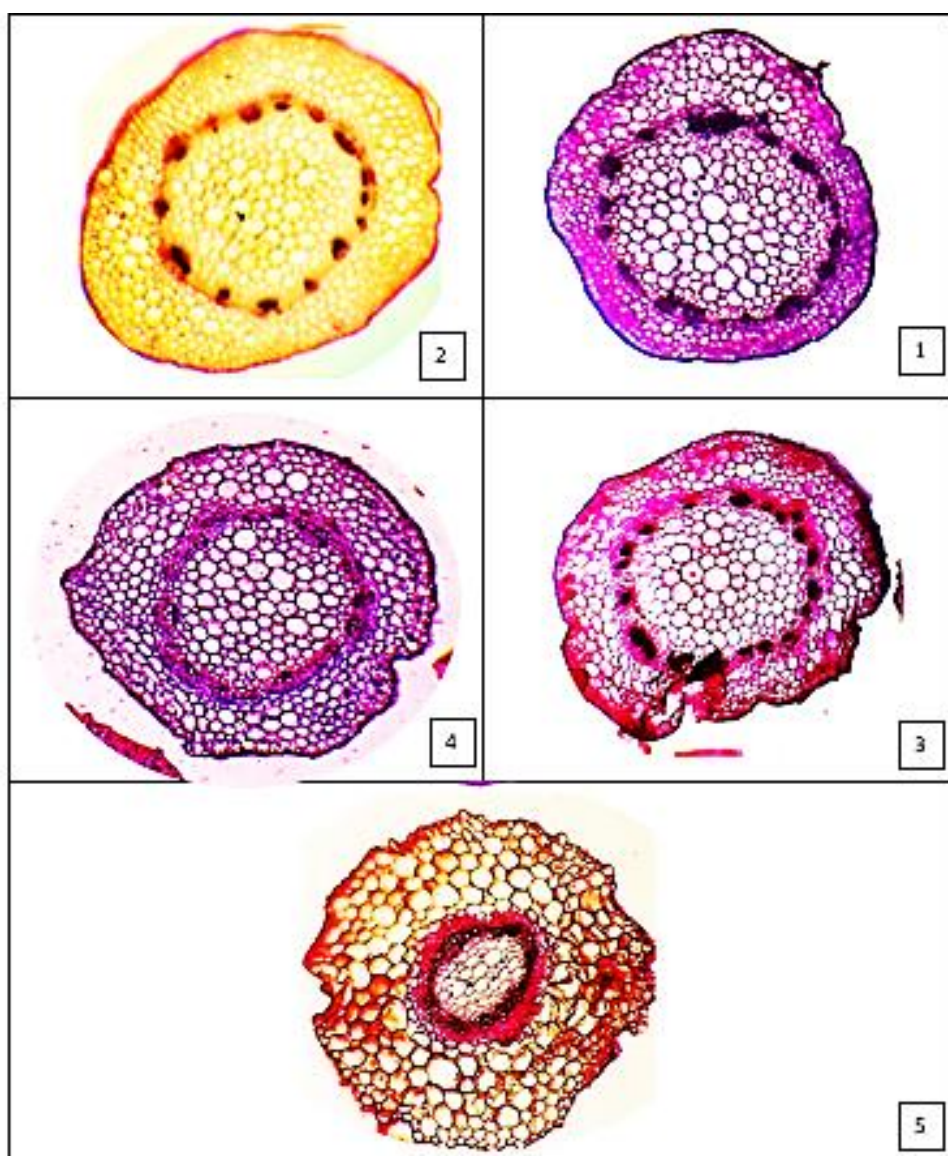


Figure 18. The effect of heavy metals on the anatomical characteristics of mustard plant stem (using 4× objective lens) 1-P1, 2-P2, 3-P3, 4-P4, 5-P5.

DISCUSSION

In contrast to less polluted areas, like residential neighborhoods, the results of the current study showed that the mustard plant's phytoremediation helped absorb and accumulate heavy metals in its leaves in areas with high concentrations of pollutants, like the cement factory and the airport street in Najaf Ashraf. This method was used as an efficient, cost-effective, and sustainable alternative to treat pollutants compared to other traditional methods because it is necessary to understand and improve the process of absorbing heavy metals in plants and properly disposing of biomass worldwide. There were no appreciable variations in the levels of phosphorus, calcium, and potassium among the study sites, according to the findings of Figures 2–6 that display the concentration of mineral nutrients in mustard leaves. This could be because mustard is one of the plants that accumulates heavy metals the most. To make it more available to the plant, mineral chelating chemicals such citric acid, oxalic acid, phenolic compounds, and others must be formed without damaging the nutrient carriers, channels, or other components [29]. The reason may also be that the accumulation of pollutants in cell walls or vacuoles is the primary detoxification process in plants [30]. Therefore, no significant differences occurred, considering that the plants in all sites carry out their activities without being affected by

these heavy elements. The ability of the mustard plant to absorb heavy elements in a way that protects its cells from the toxic concentration of heavy elements may be the cause of the cement site recording the highest rate of calcium concentration. The plant absorbs heavy elements and keeps them in the cell walls, preventing them from entering the cytoplasm [31], and this does not affect the growth of the plant. Regarding magnesium, mustard plants at the Airport Street site recorded the highest concentration, with a significant difference from the rest of the sites under study. Given that automobiles are significant contributors to pollution because of the pollutants they release through their exhausts, including lead, copper, and zinc, in addition to greenhouse gases, this could be because of the pollutants that are present on Airport Street because of incomplete combustion of gasoline or gasoline evaporation [32]. These pollutants cause a rapid response by the plant, represented by phytoremediation through rapid growth and high biomass with a deep root system, which is one of the important strategies for phytoremediation of heavy elements [33].

In places contaminated by heavy metals, plant development helps maintain the health of the soil. In addition to stabilizing heavy metals and reducing their leaching into groundwater, the plant cover also stops wind from dispersing soil particles carrying heavy metals [34]. In these plants, the root systems absorb and accumulate pollutants, such as heavy metals, and move them to the plant's aerial portions with normal growth and reproduction [35], and this is what appeared in the plants of Airport Street.

Figures 7–11 from the current study's results, which displayed the concentration of heavy elements in mustard leaves at the study sites, showed that the cement factory had the highest rates of lead, lithium, and copper when compared to other sites. This may be due to the increase in pollutants resulting from the P5 (cement factory) because of industrial activity and incomplete combustion, which leads to the emission of gases that later settle on the soils of the surrounding areas. These results are consistent with what Skuza et al. (2022) [36] found that mustard plants accumulated lead, zinc and copper in the roots, stems and leaves of the plant, and that their concentrations in the plant exceeded their concentrations in the soil. The results of our study are consistent with what was indicated by Tatu et al. (2002) [37] that the bioaccumulation factor of mustard varieties was more than one for cadmium and higher than the permissible limit for lead, which means that mustard is a good accumulator of cadmium and lead. Because mustard is a highly accumulating plant, high levels of these heavy elements are absorbed by plants, especially lead and copper, as the minerals absorbed by the roots are transferred through the stems to the leaves, which leads to an increase in their concentration in the leaves and thus reduces soil pollution with heavy metals through phytoremediation [38]. The results of the study also show significant differences caused by cadmium at the site of Al-Sabtain Restaurant and nickel at the Airport Street site compared to other sites. This may be due to the difference in fuels, as the charcoal used for grilling in restaurants and cafes contains a high percentage of cadmium that exceeds other mineral elements, such as phosphorus, potassium, calcium, and others [39]. As for nickel, a significant increase was observed in the plants of the Airport Street site. This may be due to the industrial uses of nickel materials in transportation products, vehicles, electronics, car batteries, chemicals, paints, ceramics, and many other uses. The results of the current study indicated the effect of pollutants on the anatomical characteristics of the mustard plant stem, as there was an increase in the thickness of the cortex with a decrease in the size and number of vascular bundles by changing the environment in which the plants are located. This may be due to changes in anatomical characteristics with the increase in abiotic stresses, including heavy element stress and others, as there is a narrowing of the vessels and transporting tracheids in the wood. Plants can modify their anatomical structure of the wood to regulate the hydraulic function in response to abiotic stresses, as they can create narrower and smaller channels with thicker walls to enhance the safety of transport. In addition to the decrease in the length and width of vascular bundles under the stress of heavy elements, such as lead, cadmium, and others.

CONCLUSIONS

Through our study, we did not obtain significant differences in the concentration of most of the mineral nutrients between the study sites. This means that the normal growth of the mustard plant and

the process of plant treatment of the pollutants accumulated in its tissues proceed simultaneously. However, a significant increase in the concentration of heavy elements appeared in the cement factory site, the restaurant site, and the airport road site compared to the other sites. Anatomical changes also occurred in the mustard plant stem with the change in the plant environment. A clear increase in the thickness of the mustard plant stem cortex was observed in the cement factory plants, accompanied by a clear decrease in the length and number of vascular bundles. Based on the above, we recommend the repeated cultivation of mustard plants in industrial sites, on both sides of the airport road, and in the cement factory to absorb the pollutants generated in these places.

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