

Effect of heavy metal pollution and pollution treatment with butyric acid on *Leucaena Leucocephala* and *Pithecellobium dulce* (Roxb.) Indian almonds and their effect on growth characteristics

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Abstract :

The current study was conducted during the period 10/1/2023 to 5/1/2024 in the fabric shade of the Department of Horticulture and Landscape Engineering / College of Agriculture / University of Basra, to know the efficiency of phytoremediation of Indian almond and *Leucaena* plants and their ability to absorb heavy elements by adding pollutants to the soil with irrigation water. The concentrations of each were (200,100,0) Pb mg L⁻¹ and (20,10,0) Cd mg L⁻¹. The treatment was done with Putrescine at a concentration of (500,250,0) mg L⁻¹ and the addition was by adding it to the soil. The seedlings were treated with pollutants from 10/1/2024 to 12/1/2024 for a period of three months. After 60 days had passed since the last treatment, the seedlings were treated with Putrescine at a rate of twice during the growing season with a time difference of 30 Day. The experiment was conducted according to the design of complete randomized blocks and the statistical analysis of the experimental data was conducted using the statistical program Genstat and the comparison between the averages of the treatments was done using the least significant difference and at the probability level of 0.05. The results indicated the ability of the Indian almond and *Leucaena* plants to tolerate heavy metal concentrations by measuring the indicators of vegetative and root growth. The results showed that the treatment with lead at a concentration of 20 mg L⁻¹ led to a reduction in some vegetative growth characteristics (plant height, stem diameter, number of leaves) as it reached (121.62 cm, 7.43 mm, 158.27 leaves per plant⁻¹) respectively compared to the control plants as their average reached (130.38 cm, 9.87 mm, 167.95 leaves per plant⁻¹). The treatment with cadmium at a concentration of 20 mg L⁻¹ led to a reduction in the average leaf area as it reached (594.66 cm²) compared to the control plants (4010.00 cm²), while the treatment with the butyric acid treatment led to the concentration of 250 mg L⁻¹ led to a significant increase in leaf area, which reached an average of (1482.70 cm²). Also, the treatment with putrescine at a concentration of 500 mg L⁻¹ led to a significant increase in (plant height, stem diameter, number of leaves), which reached an average of (124.29 cm, 11.28 mm, 173.19 leaves/plant⁻¹) respectively. The treatment with Cadmium at a concentration of 20 mg L⁻¹ led to a reduction in all root growth indicators, including (number of roots, root length), which reached an average of (8.67 roots/plant⁻¹, 23.03 cm) respectively, compared to the control plants (10.44 roots/plant⁻¹, 29.15 cm), while the treatment with putrescine at a concentration of 250 mg L⁻¹ led to a significant increase in the number of roots, root length, which reached an average of (11.74 roots/plant⁻¹, 28.56 cm) respectively.

Keywords: pollution, Leucocephala, Pithecellobium, Roxb

Introduction :

Leucaena leucocephala is a member of the fabales family and is a tropical and subtropical medicinal plant [11]. This tree is characterized by its contribution to improving soil properties, reducing erosion, and stabilizing sand [11].

Pithecellobium dulce (Roxb.) the Indian almond tree belongs to the legume family. It is grown in tropical regions of America, Southeast Asia, India, and Mexico. It is a small to medium-sized thorny evergreen tree that reaches a height of 15 meters and has many uses in medical fields [25]. This tree can withstand the harshest environmental conditions as it can tolerate soil salinity. Indian almond is used as a windbreak and ornamental plant [28]. Pollution is defined as the change in the chemical, physical and biological properties of the environment due to the transfer of pollutants from different sources that cause harm to humans, animals and plants [10]. The spread of pollutants in the soil and air causes many problems at high concentrations and causes harmful effects on ecosystems and on human health and other organisms. They can enter the food chain through contaminated drinking water and agricultural products, leading to their accumulation in the human body and other organisms [31].

The presence of lead in plant tissues prevents the process of photosynthesis and limits the function of stomata in leaves. High concentrations of lead cause cellular stress in the plant and prevent enzymatic activity, thus causing plant death [16] [18]. As for cadmium (cd), it is a highly toxic element. Its appearance at low concentrations is harmful to

the plant [24]. It directly affects the process of photosynthesis, transpiration, and the process of closing and opening stomata, as it moves to the cellular tissues, settles, and causes physiological and morphological changes that slow down the process of plant growth, as well as damage, deterioration, and death [20]. putrescine is one of the important biological compounds that are manufactured in the plant cell. They are compounds that belong to polyamines, which have been classified as plant growth regulators. They are non-nutritive organic compounds that may be naturally formed in the plant or manufactured in the laboratory, which work to stimulate, inhibit or modify one of the physiological processes in the plant when used at low concentrations. Growth regulators play a major role in many growth and development processes. The manufactured compounds have an effectiveness like that of plant hormones [22].

The current study aims to:

-1 Know the extent of the response of the two plant species to pollutants with heavy elements and the putrescine treatment, and which parts, the vegetative or root group, accumulate more heavy elements.

-2 Increase the efficiency of the two plant species in tolerating pollution with heavy metals by measuring their vegetative and root growth indicators.

Materials and Methods :

The current study was conducted during the period 10/1/2023 to 5/1/2024 in the shade of the Department of Horticulture and Landscape Engineering / College of Agriculture / University of Basra. The experiment was a factorial experiment with three factors. The first factor is the plant type Indian almond and *Leucaena*. The second factor is pollutants (Cd, Pb) at concentrations ((200,100.0 mg L⁻¹- Pb and (20,10.0) mg L⁻¹-

Cd) and the third factor is the pollution treatment with putrescine ((500,250.0 mg L⁻¹- Seedlings were treated with pollutants from 10/1/2023 to 12/1/2023 for a period of three months. After 60 days had passed since the last treatment, the seedlings were treated with putrescine treatment at a rate of twice during the growing season with a time difference of 30 days between them. The experiment was designed as a factorial experiment with three factors according to the complete randomized block design at a probability level of 0.05 [

Table (1): Some chemical and physical properties of the used soil.3

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Properties	Values	Unit
EC	3.53	Dsm ⁻¹
pH	8.13	---
Total N	20	Mg.kg ⁻¹
Total P	1.62	Mg.kg ⁻¹
Available K	7.23	Mg.kg ⁻¹
Total Pb	2.14	Mg.kg ⁻¹
Total Cd	0.006	Mg.kg ⁻¹
Sand	75	%
Silt	10	%
Clay	15	%
Soil Texture	Loamy sand	----

Table (2): Some chemical and physical properties of peat moss.

Characteristics	Values
pH	4.5-3.5
Organic matter (%)	97-95%
Total nitrite (%)	1%
Moisture (%)	50%
Density (g.cm)	90-60%

Studied Characteristics:

First: Vegetative Growth Indicators

-1Plant Height (cm):

The height of each plant in the experiment was measured from each experimental unit starting from the area of contact of the plant with the soil to the growing tip using a metric measuring tape and the arithmetic mean was taken.

-2Total number of leaves (leaf.plant-1):

According to the total number of leaves for each plant in the experimental unit for the treatments and the arithmetic mean was taken at the end of the experiment.

-3Leaf area (cm².plant1):

The total leaf area was measured using ImageJ program according to the method of Easlson and Bloom (2014) by taking 10 leaves from each plant of the experimental unit with a scale in a scanner and the data was entered into the computer and the readings were taken by using the program tools that represent the leaf area of the plant and according to the following equation:

Leaf area of the plant (cm²) = Leaf area (cm²)
× Number of leaves per plant

Second: Root growth indicators

-1Root length (cm)

The root length of each plant of the experimental unit was measured using a metric measuring tape and the arithmetic mean was taken.

-2Number of roots (root of plant1):

According to the number of roots for each plant of the experimental unit and the arithmetic mean was taken

Results and discussion :

-1Plant height (cm)

The data in Table (3) show the effect of the plant species, *Leucaena* and Indian almond, the concentrations of lead and cadmium pollutants, the pollution treatment, putrescine and the interaction between them on plant height. It is noted that *Leucaena* plants significantly outperformed Indian almond plants in plant height, reaching 135.34 cm and 105.91 cm, respectively. As for the effect of pollutants on plant height, the control treatment significantly outperformed the rest of the plants treated with pollutants, reaching 130.38 cm, as the lowest plant height was reached when treated with lead at a concentration of 200 mg L⁻¹, reaching 121.62 cm, while the pollution treatment of lead 100 mg L⁻¹ did not differ from the cadmium treatment 10 mg L⁻¹ (113.92 and 113.00) cm, respectively. The same table data also indicates that the putrescine treatment gave a significant superiority in the plant height trait when treated with 500 mg L⁻¹, reaching 124.29 cm over the rest of the treatment treatments, where the lowest plant height rate was in the control treatment, reaching 116.93 cm. As for the effect of the two-way interaction of plant type and pollutants, the *Leucaena* plants treated with lead at a concentration of 200 mg L⁻¹ were significantly superior and gave the highest height of 146.77 cm, while the lowest plant height was recorded by the Indian almond plants when treated with lead at a concentration of 100 mg L⁻¹, reaching 89.88 cm. The effect of the interaction between the plant species and the putrescine treatment was significant, as the *Lucaena* plants treated with

the puterscine treatment 500 mg L⁻¹ outperformed by giving the highest height rate of 139.18 cm, which did not differ significantly with the Lucinia plants treated with puterscine 250 mg L⁻¹, the puterscine treatment 250 mg L⁻¹, as the height in them reached (136.86, (104.46 cm. Compared to the lowest rate recorded by the Indian almond plants in the control treatment, as the height rate in them reached 103.86 cm. As for the interaction between the puterscine treatment and the pollutants, it is noted from the data in the table above that the interaction between the control treatment and the puterscine treatment at a concentration of 500 mg L⁻¹ outperformed significantly and gave the highest height of 133.66 cm, which did not differ significantly with (the interaction treatment between the control and the puterscine treatment at a concentration of 250 mg L⁻¹, the interaction treatment Cadmium concentration 20 mg L⁻¹ and puterscine 500 mg L⁻¹) as the height rate reached (133.66, (132.05 cm in this trait compared to the lowest rate recorded by the lead treatment 100 mg L⁻¹ as it reached 110.16 cm. As for the effect of the triple interaction between the plant type, pollutants and puterscine treatment, it had a significant effect on this trait, as the treated Leucaena plants with lead concentration 200 mg L⁻¹ and puterscine concentration 500 mg L⁻¹ outperformed by giving the highest height as it reached 150.33 cm, which did not differ significantly with (lead treatment 200 mg L⁻¹ - puterscine 250 mg L⁻¹ -, control treatment and puterscine 500 mg L⁻¹ - and control treatment and puterscine 250 mg L⁻¹ -, control treatment and lead 200 mg L⁻¹ - mg L⁻¹), as the plant height rate in them reached (146.67,144.33,143.33,140.92) cm, compared

to the lowest average height of Indian almond plants when treated with lead 100, which reached (88.00) cm. These results are similar to what was reached by [29] in a study on the toxic effect of lead and cadmium on the phenotypic and chemical characteristics of fenugreek plants, where it showed significant differences in the characteristic of plant height, as treatment with lead and cadmium led to a reduction in plant height, which reached 7.3 cm when treated with cadmium, while plant height when treated with lead reached 6.2 cm compared to the control treatment, which reached 8.6 cm. [4]. indicated that the decrease in seedling length may be attributed to the decrease in the presence of meristematic cells and some important and necessary enzymes that are present in the cotyledon and endosperm region. These results are similar to what was mentioned. These results are consistent with what was found by [19], where the height of the soybean plant decreased from 23 cm at the control concentration to 16 cm when treated with lead at a concentration of 100 mg. kg⁻¹ and to 13.66 cm when treated with lead at a concentration of 150 mg. kg⁻¹. One of the most common and important symptoms is the occurrence of dwarfing in plants exposed to different concentrations of cadmium, as the process of opening and closing the stomata, transpiration and photosynthesis in the plant is affected by heavy elements, including cadmium, as this element causes a decrease in the growth rate, which in turn leads to early dwarfing of the plant. The reason for the decrease in plant growth is attributed to inhibition of plant growth, and these results are similar to what was found by [27]. These results are similar to what was reached by

(Anayat et al., 2014) that cadmium affected the height of the sweet bean plant. The results shown in Table (3) show that adding putrescine to the soil had a positive effect on the vegetative growth characteristics because putrescine is one of the polyamine compounds that represent a new class of growth materials, as it is also an anti-aging and anti-environmental stress material that the plant is exposed to due to its acidic properties, antioxidant properties, and ability to stabilize membranes and cell walls [32]. Adding polyamines leads to increased nutrient absorption, especially potassium, which plays an important vital role in the photosynthesis process by improving growth, as well as photosynthetic pigments and absorption of CO₂ gas. These compounds have the ability to improve cell division and elongation [13]. They are also a source of nitrogen that stimulates growth [27]. This result is

consistent with the findings of [21] in a study of the response of narcissus to spraying with putrescine and magnesium and their effect on the vegetative, floral and chemical growth characteristics of leaves. Spraying with putrescine at a concentration of 100 mg.L⁻¹ led to a significant increase in all vegetative growth indicators. These results are similar to what was found by [8] in a study of the response of two leek varieties to mineral and biological fertilization and spraying with putrescine in the indicators Growth and yield, as the results showed that spraying with putrescine at a concentration of 150 mg/L-1 had a significant effect on plant height, as it gave the highest height of 41.33 cm compared to the lowest height recorded by the control treatment of 37.13 cm

Table (3) Effect of the plant species, Leucaena and Indian almond, concentrations of lead and cadmium pollutants, butyrate pollution treatment, and their interaction on plant height (cm).

Plants	pollutants (mg.L ⁻¹)	Pollution treatment (putrescine) mg.l ⁻¹			Average plant	Average pollutants
		0	250	500		
Leucaena	0 con.	127.00	143.33	144.33	135.34	130.38
	100 pb	132.33	140.67	140.92		113.92
	200 pb	143.33	146.67	150.33		121.62
	10 cd	124.00	124.00	125.33		113.00
	20 cd	123.33	129.67	135.00		126.00
Indian almonds	0 con.	120.67	124.00	123.00	105.91	4.09
	100 pb	88.00	89.33	92.33		
	200 pb	99.33	90.67	102.67		
	10 cd	92.33	97.00	99.00		
	20 cd	119.00	121.33	130.00		
		8.4			2.59	
Average pollution treatment (putrescine)		116.93	120.66	124.29	Average interaction between plant species	

	3.17			and pollutants	
Average interaction between contaminants and the treatment (biotin)				Leucaena	Indian almonds
0	123.83	133.66	133.66	138.22	122.55
100	110.16	115.00	116.62	137.97	89.88
200	121.33	117.50	126.05	146.77	97.56
10	108.16	118.67	112.17	124.44	96.11
20	121.16	125.05	132.05	129.33	123.44
	6.09			5.79	
Average interaction between plant species and pollution treatment (puterscine)					
Leucaena	130.00	136.86	139.18		
Indian almonds	103.86	104.46	109.40		
	4.48				

-2Number of leaves (leaf.plant-1(

Table (4) shows the effect of the plant species Leucaena and Indian almond, the concentrations of lead and cadmium pollutants, the pollution treatment puterscine, and the interaction between them in the number of leaves. It is noted that Indian almond plants are significantly superior to Leucaena plants, reaching 312.56 and 12.87 leaves.plant-1 respectively. The reason for this difference may be due to the genetic variation between the two species. As for the effect of pollutants, the control treatment outperformed the other treatments, reaching 167.95 leaves.plant-1 compared to the lowest rate recorded by the lead treatment of 200 mg L-1-, which reached 158.27 leaves.plant1-. The table also indicates that the puterscine treatment was significantly superior, as the puterscine treatment with a concentration of 500 mg L-1- was superior, reaching 173.19

leaves.plant-1 compared to the lowest rate recorded by the control treatment of 147.76 leaves.plant1-. As for the effect of the two-way interaction between the plant type and pollutants, it gave a significant effect, as the Indian almond plants outperformed the control treatment, reaching 321.56, which did not differ significantly with (lead treatment of 100 mg L-1, lead treatment of 200 mg L-1, cadmium treatment of 10 mg L-1, cadmium treatment of 20 mg L-1-), as the average number of leaves in them reached (315.80,303.20,314.90, (307.33 leaves. plant1-compared to the lowest rate recorded by Leucaena plants when treated with cadmium concentration 20 mg L-1-, which amounted to 10.55 leaves. plant1-. As for the two-way interaction between the plant type and the puterscine treatment, the Indian almond plants treated with puterscine 500 mg L-1-outperformed, as it amounted to 331.54

leaves.plant⁻¹, which did not differ significantly with the butyrosin 250 mg L⁻¹ treatment, as it amounted to 321.20 compared to the lowest rate recorded by *Leucaena* plants when treated with the control, as it amounted to 10.58 leaves.plant⁻¹, which did not differ significantly with (the putrescine 500 mg L⁻¹ treatment, the putrescine 250 mg/L⁻¹ treatment, as the average number of leaves in them amounted to (14.85, 13.19) leaves.plant⁻¹. While the effect of the binary interaction between pollutants and the putrescine treatment was significant, as the lead treatment of 100 mg L⁻¹ and putrescine 500 mg L⁻¹ outperformed, reaching 179.35 leaves.plant⁻¹, which did not differ significantly with (the control treatment and putrescine 500 mg L⁻¹, the cadmium treatment of 20 mg L⁻¹ and putrescine 250 mg L⁻¹, the cadmium treatment of 10 mg L⁻¹ and putrescine 500 mg L⁻¹, the lead treatment of 100 mg L⁻¹ and biotrichin 250 mg L⁻¹, the control treatment and putrescine 250 mg L⁻¹, the cadmium treatment of 10 mg L⁻¹ and putrescine 250 mg L⁻¹), as the average number of leaves in them reached (175.85,175.30,175.00,172.91,169.65,160.85) leaf.plant⁻¹-compared to the lowest rate recorded by plants treated with cadmium 20 mg L⁻¹- and not treated with putrescine, which amounted to 137.40 leaf.plant⁻¹. As for the effect of the triple interaction, the Indian almond plants treated with lead 100 mg L⁻¹- and putrescine 500 mg L⁻¹- and putrescine 500 mg L⁻¹- outperformed, as it amounted to 342.00 leaf. plant⁻¹--compared to the lowest rate recorded by *Lucaena* plants when treated with cadmium 20 mg L⁻¹- which amounted to 9.10 leaf.plant⁻¹.-

The number of leaves was affected by heavy metals added to the soil, especially cadmium, as cadmium affected the number of leaves in the plant. This is due to the decrease in growth as a result of the toxicity of heavy elements present in the soil. High concentrations of pollutants cause a deterioration in the physiological state of the plant and inhibit the effectiveness of enzymes. Plants exposed to pollutants have smaller and fewer leaves [17]. These results are similar to what [2], reached when studying the efficiency of the Shabawi and *Petunia* plants in absorbing some heavy elements and their effect on growth characteristics. The number of leaves decreased in both species, and the higher the concentration of heavy elements in the soil. These results are consistent with what was found by [24] in his study on the phytoremediation of soil contaminated with heavy metals using Indian mustard. He recorded a decrease in the number of leaves when the plant was treated with cadmium 15 mg.kg⁻¹, as it reached 60 leaves.plant⁻¹-compared to the control treatment, in which the average number of leaves was 127 leaves.plant⁻¹-. Many studies have shown that exposure to lead causes deterioration of the plasma membrane, decreased absorption of mineral elements, and affects chlorophyll in the plant, which leads to a small leaf area and a small number of leaves [2].The result of the study (Khader, 2014) when studying the plant treatment of soil contaminated with heavy elements using Indian mustard showed that the total number of leaves decreased when treated with lead 300 mg kg⁻¹, reaching 57 leaves/plant⁻¹, compared to control plants, which had an average number of leaves of 130 leaves/plant⁻¹. The results of the same table

show that adding the puterscine treatment to the soil had a positive effect on the number of leaves, and the reason for this is that it stimulates some physiological responses, especially activating the process of photosynthesis and manufacturing hormones and enzymes. These results are similar to what was reached by [29] when studying the effect of spraying with puterscine and indole acid on the plant *Antirrhinum majus* L., where he concluded that spraying with puterscine at a concentration of 150 mg L⁻¹ achieved an increase in the number of leaves compared to control plants. This result is consistent with what was found by [21] in his study on the

response of narcissus to spraying with puterscine and magnesium chelate and their effect on some vegetative, floral and chemical growth traits of leaves, where spraying with puterscine at a concentration of 100 mg L⁻¹ led to a significant increase in the number of leaves trait compared to those control plants. This result is similar to what was reached by [5] in his study on the effect of spraying with some plant growth regulators on increasing the tolerance of date palms to salinity, where spraying with puterscine led to a significant increase in the number of fronds compared to control plants.

Table (4) The effect of the plant species *Leucaena* and Indian almond and the concentrations of lead and cadmium pollutants and the pollution treatment puterscine and the interaction between them on the number of leaves (leaf. plant-1.)

Plants	pollutants (mg.L ⁻¹)	Pollution treatment (puterscine) mg.l ¹			Average plant	Average pollutants
		0	250	500		
Leucaena	0 con.	11.70	15.30	16.00	12.87	167.95
	100 pb	11.30	13.12	16.70		164.75
	200 pb	10.50	14.24	15.30		158.27
	10 cd	10.33	13.00	14.00		163.67
	20 cd	9.10	10.30	12.27		158.94
Indian almonds	0 con.	305.00	324.00	335.70	312.56	15.47
	100 pb	272.70	332.70	342.00		
	200 pb	281.30	300.30	328.00		
	10 cd	300.00	308.70	336.00		
	20 cd	265.70	340.30	316.00		
		40.79			10.05	
Average pollution treatment (puterscine)		147.76	167.19	173.19	Average interaction between plant species and pollutants	
		10.53				
Average interaction between contaminants and the treatment (biotin)					Leucaena	Indian almonds
0		158.35	169.65	175.85	14.33	321.56

100	142.00	172.91	179.35	13.70	315.80
200	145.90	157.27	171.65	13.34	303.20
10	155.16	160.85	175.00	12.44	314.90
20	137.40	175.30	164.13	10.55	307.33
	19.25			22.70	
Average interaction between plant species and pollution treatment (puterscine)					
Leucaena	10.58	13.19	14.85		
Indian almonds	284.94	321.20	331.54		
	17.13				

-3Leaf area (cm² (

Table (5) shows that Indian almond plants were significantly superior to Leucaena plants, reaching 1938.80, 118.93 cm², respectively. The reason for the difference between them is due to their genetic variance. As for the effect of pollutants, the control treatment was superior in leaf area to the rest of the treatments, reaching 4010.00 cm², while it did not differ significantly with the lead treatment at a concentration of 100 mg L⁻¹, reaching 3877.00 cm², compared to the lowest rate in the cadmium treatment at a concentration of 20 mg L⁻¹, reaching 594.66 cm². While the table data showed that the puterscine pollution treatment gave a significant superiority in this characteristic, as puterscine concentration of 250 mg L⁻¹ was significantly superior, reaching 1482.70 cm², which did not differ significantly from puterscine concentration of 500 mg L⁻¹, reaching 810.30 cm², while the lowest value was recorded by the control treatment, reaching 793.60 cm². As for the effect of the two-way interaction between the plant species and pollutants, it gave a significant effect on the leaf area trait, as the Indian almond plants outperformed the control treatment over the rest of the pollutant concentrations, reaching 2553.66 cm², which did not differ significantly with (lead treatment 100 mg L⁻¹, lead treatment 200 mg L⁻¹, cadmium treatment 10 mg L⁻¹), as the average leaf area in them reached (2467.33, 1896.66, (1705.33 cm²) compared to the lowest rate recorded by the Leucaena plants when treated with lead at a concentration of 200 mg L⁻¹, which reached 113.00 cm². The data in the table indicate that the two-way interaction between the plant species and the puterscine treatment gave a significant superiority, as the Indian almond plants treated with puterscine 250 mg L⁻¹ outperformed the rest of the other concentrations, reaching 2833.80 cm², compared to the lowest rate recorded by the plants. The data of the same table showed that the interaction between pollutants and the butyric acid treatment gave a significant difference, as the control plants outperformed with the highest rate of 2440.00 cm², which did not differ significantly with (lead treatment 100 mg L⁻¹, which reached 2108.00 cm², lead treatment 200 mg L⁻¹, cadmium treatment 10 mg L⁻¹), as the average leaf area in them reached (2108.00, 1157.50, (1020.00 cm²) compared to the lowest rate recorded by the plants treated with cadmium 20 mg L⁻¹ and not treated with butyric acid treatment, which reached 516.00 cm². While the triple interaction was significant, the Indian almond plants outperformed the control and the 250 mg L⁻¹ treatment with puterscine, with the highest rate

reaching 4748.00 cm², compared to the lowest rate recorded by the *Leucaena* plants when treated with a concentration of 200 mg L⁻¹ and not treated with putrescine, which reached 83.00 cm². The results of the table show that the leaf area of the plant was affected by the addition of heavy elements to the soil, especially cadmium, as the Indian almond plants showed greater resistance to the toxicity of heavy elements, as cadmium affected the reduction of leaf area. The reason for this is that cadmium is a highly toxic element, even if it appears in different concentrations, it affects the process of opening and closing the stomata, transpiration and photosynthesis [1]. Heavy elements are responsible for causing necrosis on the surface of the plant leaf as a result of local death of some damaged leaf cells, which leads to a reduction in leaf area [23]. This result is similar to what was found by [24] regarding his study on the addition of heavy elements lead and cadmium to the soil, as the results showed a decrease in leaf area when the plant was treated with different concentrations of elements compared to the control treatment. The growth, division and expansion processes are affected by the addition of heavy elements, which leads to a decrease in the leaf area of the plant when the plant is treated with high levels of lead. The process of opening and closing the stomata is controlled by the plant hormone abscisic acid (ABA). The presence of lead ions causes the accumulation of ABA in the roots and upper parts of the plant, which leads to the closure of the stomata and insufficient concentration of carbon dioxide (CO₂) and weakness and absorption of essential elements such as iron and manganese, as well as increased activity of the enzyme Chlorophyllase, which causes the decomposition of chlorophyll [4]. This result is similar to what was reached by [7] about his study on the effect of lead and nickel on the growth and physiological characteristics of the sunflower plant, where the study showed a significant decrease in the leaf area of the plant when exposed to high concentrations of lead compared to the control treatment. These results are similar to what was reached by [6] in his study on the response of local orange trees to the myxoplasma fungus and spraying with putrescine, where the results of the study showed that the average leaf area of the plant increased as a result of adding putrescine to the plant. These results are similar to what was found by [26] in his study on the foliar spraying of putrescine and salicylic acid on the vegetative, floral and tuberous root growth characteristics of the *ranunculus* plant, where the study showed a significant increase in the average leaf area of the plant compared to the control treatment. This is because adding putrescine causes an increase in the vegetative growth characteristics that are due to the absorption of nutrients, especially potassium, which plays an important role In the process of photosynthesis and absorption of CO₂, polyamine compounds have the ability to increase the effectiveness of physiological functions and increase the efficiency of roots in absorbing nutrients from the soil [33].

Table (5) Effect of the plant species Leucaena and Indian almond, concentrations of lead and cadmium pollutants, puterscine pollution treatment, and their interaction on leaf area (cm².)

Plants	pollutants (mg.L ⁻¹)	Pollution treatment (puterscine) mg.l ⁻¹			Average plant	Average pollutants
		0	250	500		
Leucaena	0 con.	107.00	132.00	120.00	118.93	4010.00
	100 pb	104.00	128.00	120.00		3877.00
	200 pb	83.00	125.00	131.00		1004.83
	10 cd	107.00	141.00	131.00		915.83
	20 cd	109.00	132.00	114.00		594.66
Indian almonds	0 con.	1413.00	4748.00	1500.00	1938.80	956.60
	100 pb	1788.00	4088.00	1526.00		
	200 pb	1658.00	2190.00	1842.00		
	10 cd	1644.00	1899.00	1573.00		
	20 cd	923.00	1244.00	1046.00		
		2343.20			605.00	
Average pollution treatment (puterscine)		793.60	1482.70	810.30	Average interaction between plant species and pollutants	
		681.00				
Average interaction between contaminants and the treatment (biotin)					Leucaena	Indian almonds
0		760.00	2440.00	810.00	119.66	2553.66
100		946.00	2108.00	823.00	117.33	2467.33
200		870.50	1157.50	986.50	113.00	1896.66
10		875.50	1020.00	852.00	126.33	1705.33
20		516.00	688.00	580.00	118.33	1071.00
		1456.90			1352.80	
Average interaction between plant species and pollution treatment (puterscine)						
Leucaena		102.00	131.60	123.20		
Indian almonds		1485.20	2833.80	1497.40		
		1047.90				

-4Number of roots (roots/plant-1)

The data in Table (7) show that Indian almond plants are significantly superior to Leucaena plants, as they reached (11.54, 8.18) roots/plant-1, respectively. As for the effect of

pollutants on the number of roots, the comparison treatment outperformed the rest of the pollutants, as it reached 10.44 roots/plant-1, which did not differ significantly with the

lead treatment at a concentration of 100 mg L⁻¹, as it reached 10.39 roots/plant⁻¹. The same table also indicates that the average of the putrescine treatment at a concentration of 500 mg L⁻¹ significantly outperformed the rest of the concentrations, as it reached 11.74 roots/plant⁻¹, compared to the lowest number of roots in the control treatment, as it reached 8.42 roots/plant⁻¹. As for the effect of the two-way interaction between the plant type and the pollutants, the data in the same table show the superiority of the Indian almond plants in the control treatment, as it reached 12.26 roots/plant⁻¹, which did not differ significantly from (cadmium treatment 10 mg L⁻¹, lead treatment 200 mg L⁻¹, lead 100 mg L⁻¹), as the average number of roots reached (12.00, 11.73, 11.46) roots/plant⁻¹, respectively, while the lowest number of roots was in the control plants. The leucaena treated with cadmium 20 mg L⁻¹ reached 7.07 roots/plant⁻¹. While the binary interaction between the plant type and the putrescine treatment gave a significant superiority, as the Indian almond plants treated with putrescine 500 mg L⁻¹ outperformed the rest of the treatments, reaching 14.19 roots/plant⁻¹, compared to the lowest rate recorded by the 1 plants in the control treatment, reaching 7.28 roots/plant⁻¹. The binary interaction between the pollutants and the putrescine treatment also achieved a significant superiority, as the plants treated with cadmium 10 mg L⁻¹ and putrescine 500 mg L⁻¹ outperformed, reaching 12.82, which did not differ significantly in (the lead 200 mg L⁻¹ and butyrene 500 mg L⁻¹ treatment, and the lead 100 mg L⁻¹ and putrescine 500 mg L⁻¹ treatment, the control treatment), as the average number of Roots (12.39, 11.80, 11.53) roots/plant⁻¹ compared

to the lowest rate recorded by the cadmium treatment of 20 mg L⁻¹-, which amounted to 7.33 roots/plant⁻¹-. While the triple interaction coefficient gave a significant superiority, as the Indian almond plants treated with cadmium 10 mg L⁻¹- and putrescine 500 mg L⁻¹- were significantly superior, amounting to 16.67 roots/plant⁻¹- compared to the lowest rate recorded by the Leucaena plants when treated with cadmium 20 mg L⁻¹-, which amounted to 6.00 roots/plant⁻¹-. The data in the table show that the number of roots was affected by the heavy elements added to the soil, as lead affected the reduction in the number of roots. The reason for this is that the roots are more sensitive to lead than the stem. This is explained by the fact that the roots are the organ that absorbs toxic elements earlier due to the increased accumulation of heavy elements in them compared to other plant organs. It is worth noting that the growth of secondary or lateral roots grows faster than the main root, and the reason for this is that the vegetative group is larger when the secondary roots begin to form. This result is similar to what was found by [4], as high concentrations of lead contribute to stopping growth processes in plants after 21 hours of treatment, as it works to reduce the frequency of division in the meristematic region and thus causes a delay in the root growth process. Inhibition of root growth is an important symptom of cadmium toxicity. Leucaena plants were affected when treated with lead, unlike Indian almond plants, and the severity of symptoms increases with increasing concentrations. This result is similar to what was found by [4] that the cadmium element is rapidly bound to the cell wall, causing disruption and damage to physiological processes. The more the plant

is able to remove the toxicity of the cadmium element from its cells, the more resistant the plant is to the toxicity of the cadmium element. In addition, the effect of heavy metals disrupts the selective permeability of cell membranes, which causes a direct decrease in the absorption surface and the formation of root hairs. Exposure to long periods and medium and high concentrations harms the mechanism of water absorption and ion transfer due to the dissolution and decomposition of the terminal root cells. The

data in Table (7) indicate that adding putrescine to the soil had a positive effect on the number of roots. These results are consistent with what was found by [26] (that spraying putrescine at a concentration of 150 mg L⁻¹ led to an increase in the number of tuberous roots. This is because polyamine compounds have the ability to increase the efficiency of metabolic processes in plants. As a result, the physiological functions of these plants improve due to the increased effectiveness of the roots in absorbing nutrients from the soil

Table (7) Effect of the plant species *Leucaena* and Indian almond, concentrations of lead and cadmium pollutants, and the pollution treatment putrescine and the interaction between them on the number of roots (plant root 1.-

Plants	pollutants (mg.L ⁻¹)	Pollution treatment (putrescine) mg.l ⁻¹			Average plant	Average pollutants
		0	250	500		
Leucaena	0 con.	7.88	8.33	9.67	8.18	10.44
	100 pb	8.58	8.92	10.46		10.39
	200 pb	7.30	8.00	9.31		9.96
	10 cd	6.67	7.49	8.97		9.85
	20 cd	6.00	7.18	8.04		8.67
Indian almonds	0 con.	10.67	12.72	13.39	11.54	0.99
	100 pb	10.05	11.20	13.14		
	200 pb	9.45	10.27	15.48		
	10 cd	9.00	10.33	16.67		
	20 cd	8.67	9.86	12.31		
		3.04			0.63	
Average pollution treatment (putrescine)		8.42	9.43	11.74	Average interaction between plant species and pollutants	
		0.77				
Average interaction between contaminants and the treatment (biotin)					Leucaena	Indian almonds
0		9.27	10.52	11.53	8.62	12.26
100		9.31	10.06	11.80	9.32	11.46
200		8.37	9.13	12.39	8.20	11.73

10	7.83	8.91	12.82	7.71	12.00
20	7.33	8.52	10.17	7.07	10.28
	1.37			1.14	
Average interaction between plant species and pollution treatment (puterscine)					
Leucaena	7.28	7.98	9.29		
Indian almonds	9.56	10.87	14.19		
	1.09				

Root length (cm)

The data in Table (8) show the effect of the plant species *Leucaena* and Indian almond, the concentrations of lead and cadmium pollutants, and the pollution treatment puterscine and the interaction between them on the root length, as it is noted that Indian almond plants are significantly superior to *Leucaena* plants, as they reached 27.97, 25.01 cm, respectively.

The table above also indicates that the effect of pollutants, as the control treatment outperformed the rest of the other pollutants in the root length trait, as it reached 29.15 cm, which did not differ significantly from the lead treatment at a concentration of 100 mg L-1, as it reached 29.06 cm, compared to the lowest rate recorded by the cadmium treatment at a concentration of 20 mg L-1, as it reached 23.03 cm. While the average puterscine treatment at a concentration of 250 mg L-1 gave a significant superiority over the rest of the concentrations, as it reached 28.56 cm, compared to the lowest rate recorded by the control treatment of 24.31 cm. As for the effect of the two-way interaction between plant species and pollutants, it was significantly superior, as the Indian almond plants treated with lead 100 mg L-1 were superior, reaching 31.59 cm, which did not

differ significantly from (lead treatment 200 mg L-1, control treatment, and *Leucaena* plants in the control treatment), as the average root length reached (29.77, 29.64, 28.66) cm, compared to the lowest rate recorded by the cadmium 20 treatment, which reached 22.79 cm. While the two-way interaction between plant species and the puterscine treatment led to a significant superiority, as the Indian almond plants treated with puterscine 250 mg L-1 were superior, reaching 29.80 cm, which did not differ significantly from the puterscine treatment 500 mg L-1, which reached 28.28 cm, compared to the lowest rate recorded by *Leucaena* plants in the control treatment, which reached 22.80 cm. The table above indicates that the binary interaction between pollutants and the puterscine treatment gave a significant superiority, as the plants treated with lead 100 mg L-1 and puterscine 250 mg L-1 outperformed, reaching 30.79, which did not differ significantly with (the control treatment and puterscine 250 mg L-1, the treatment of lead 100 mg L-1 and puterscine 500 mg L-1, the control treatment and puterscine 500 mg L-1, the treatment of lead 200 mg L-1 and puterscine 250 mg L-1, the control treatment not treated with puterscine, the treatment of lead 200 mg L-1 and

puterscine 500 mg L⁻¹) as the average root length reached (30.33, 29.50, 29.19, 28.02, 27.50) cm, respectively, compared to the lowest rate recorded by the treatment of cadmium 20 mg L⁻¹ and the non- Treatment with puterscine, as it reached 20.16 cm. While the triple interaction was significant, as the Indian almond plants treated with lead 100 mg L⁻¹ and puterscine 250 mg L⁻¹ outperformed, as it reached 34.00 cm, compared to the lowest rate recorded by the *Leucaena* plants when treated with cadmium 20 mg L⁻¹ and not treated with puterscine, as it reached 19.00 cm. It is clear from the data in the table that the root length was affected by the heavy elements added to the soil. Indian almond plants showed more resistance to heavy element toxicity than *Leucaena* plants, as the cadmium element affected the root length. The reason for this is that exposure to high concentrations of cadmium causes a negative effect on root growth. The reason for the root stopping growth is attributed to the cessation of mitosis of the cell and the destruction of Golgi bodies and the change in the biometabolism of sugars, which leads to many disorders and deformities of chromosomes and the diameter and number of vascular bundles [4]. also showed that treatment with lead affects root growth, and the decrease in root

length was explained by the decrease in cell division in the meristematic region of plant roots, as lead reduces the process of vital division. This result is similar to what [7] found when treated with concentrations of lead (300, 200, 100, 0) mg L⁻¹. He noted a significant decrease in root length and attributed the reason for this to the negative effect caused by heavy metal pollution, which negatively affected the processes of cell division and expansion and hormonal regulation of growth in plants, which in turn affect the processes of photosynthesis, respiration, amino acid construction, photosynthesis, and protein. As it is clear from the data in the table, adding puterscine to the soil has a positive effect on the root length trait because it improves the division and elongation of plant cells, thus stimulating internal stimuli such as auxins, gibberellins and cytokinins, while reducing the amount and effectiveness of inhibitors such as abscisic acid (ABA) [15]. This result is similar to what was reached by [] in his study on the effect of puterscine, ascorbic acid and thiamine on the *Gladiolus* plant. And what was reached by [30] in his study on the physiological response to tryptophan and puterscine on the *Ain Al-Bazun* plant.

Table (8) Effect of the plant species *Leucaena* and Indian almond, concentrations of lead and cadmium pollutants, the pollution treatment puterscine, and the interaction between them on root length (cm.)

Plants	pollutants (mg.L ⁻¹)	Pollution treatment (puterscine) mg.l ¹			Average plant	Average pollutants
		0	250	500		
Leucaena	0 con.	27.00	30.67	28.33	25.01	29.15
	100 pb	25.00	27.58	27.00		29.06
	200 pb	21.33	26.05	24.00		27.24
	10 cd	21.67	25.00	23.21		23.92
	20 cd	19.00	27.30	22.09		23.03
Indian almonds	0 con.	29.04	30.00	29.88	27.97	1.90
	100 pb	28.78	34.00	32.00		
	200 pb	26.00	32.33	31.00		
	10 cd	24.00	27.00	25.41		
	20 cd	21.33	25.67	23.15		
		4.45			1.24	
Average pollution treatment (puterscine)		24.31	28.56	26.60	Average interaction between plant species and pollutants	
		1.83				
Average interaction between contaminants and the treatment (biotin)					Leucaena	Indian almonds
0		28.02	30.33	29.10	28.66	29.64
100		26.89	30.79	29.50	26.52	31.59
200		25.05	29.19	27.50	23.79	29.77
10		22.83	26.00	24.31	23.29	25.47
20		20.16	26.33	22.62	22.79	23.38
		3.56			2.72	
Average interaction between plant species and pollution treatment (puterscine)						
Leucaena		22.80	27.32	24.92		
Indian almonds		25.83	29.80	28.28		
		1.88				

Conclusions:

We conclude from the current study that the Indian almond plant is more resistant than the *Leucaena* plant in terms of damage caused by lead and cadmium pollutants, and that high concentrations of them have negatively

affected all vegetative and root growth characteristics, and that the pollution treatment with putrescine at a concentration of 500 mg L⁻¹ is more effective than a concentration of 250 mg L⁻¹ in reducing the damage caused by different concentrations of pollutants Cd, Pb

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