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Physiological and Biochemical Responses of Fava Bean (*Vicia faba* L.) to Cadmium Stress

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ABSTRACT

This research was conducted on October 26, 2023, in the open field of the Biology Department, Faculty of Science and Health, Koya University, Kurdistan Region-Iraq. The experiment with randomized complete design (C.R.D) with three replications. The objective of the present study was to investigate the effect of cadmium chloride ($CdCl_2$) applied to soil at concentrations of four levels (0, 5, 25, and 50 mg•kg^{-1}) on the seed performance, growth traits, and the physiological and biochemical traits of fava bean. The results showed that cadmium (Cd) contamination had no significant effect on seed performance. However, vegetative growth properties, including plant height, stem diameter, leaf area, and the percentage of nodule dry matter, decreased as Cd concentrations increased. Interestingly, a low Cd concentration (15 mg·kg^{-1}) slightly improved morphological growth, whereas a higher concentration (150 mg·kg^{-1}) significantly reduced these traits. The number of nodules per plant also decreased with increasing Cd levels (15, 75, and 150 mg·kg^{-1}) compared to the control. In contrast, cadmium (Cd) application had no significant effect on leaf number, root length, root diameter, or the dry matter of both shoots and roots. Regarding physiological and biochemical traits, cadmium (Cd) contamination had no significant impact on chlorophyll a, chlorophyll b, peroxide levels, ascorbic acid, total proline, or total carbohydrates. The concentrations of Cd did not significantly alter the leaf content of photosynthetic pigments or the activity of certain enzymatic and non-enzymatic antioxidants. However, catalase enzyme activity and total carotenoid levels significantly increased at 15 mg·kg^{-1} compared to other treatments. Furthermore, cadmium exposure had no significant effect on stomatal traits, including stomatal number, length, and width on both the adaxial and abaxial surfaces of Vicia faba plants. These findings suggest that while low Cd concentrations may have minimal or slightly beneficial effects on some growth traits, higher Cd levels negatively impact key growth and biochemical parameters in fava beans.

***Keywords*:** Cadmium stress, Seed performance, Physiochemical traits and Vicia faba.

INTRODUCTION

Fava bean (*Vicia faba*) is a useful plant from the legume family (Fabaceae) that can grow in different climates worldwide [1]. It is widely grown in places like the Mediterranean, China, Africa, Europe, the Middle East and Asia. Fava beans are an important food for both people and animals. Because they are nutritious and easy to grow, they help support farming and food supply in many regions. When used in crop rotation or intercropped with cereals, fava beans offer several agronomic, economic and environmental benefits. They help reduce the need for inorganic fertilizers in subsequent crops by enriching soil fertility through biological nitrogen fixation. Additionally, they improve plant yields and disrupt cycles of diseases and pests, making them a valuable component of sustainable farming systems. Fava beans also play a physiological role as a precursor for dopamine, a key neurotransmitter [2]. Fava beans are rich in protein, carbohydrates, minerals, vitamins, and other beneficial plant compounds. Although, they also contain certain anti-nutritional compounds that may affect digestibility and nutrient absorption [3].

Many cities worldwide have conducted extensive studies on soil pollutants. However, in developing countries, there is relatively little focus on this issue. In this region, soil pollution levels are particularly high, especially due to cadmium, lead, zinc, copper, and polycyclic aromatic hydrocarbons (ΣPAH), which are commonly found in roadside, commercial, and industrial areas [4]. Cadmium (Cd) is not needed by plants, and its effects on plant growth are not well understood [5]. The National Food Safety Standard sets the maximum safe Cd level for leafy vegetables at 0.2 mg•kg^{-1} (fresh weight). To keep food safe, it is important to check Cd levels in different soils. Research shows that Cd levels in soils can range from 0.12 to 1.7 mg•kg^{-1} [6]. Plants growing in Cd-contaminated soil absorb this metal, leading to its buildup in edible parts, which can enter the food chain [7]. Cd is highly toxic to crops and can harm both human and animal health [8]. As a common environmental pollutant, Cd threatens farming and food safety [9]. Monitoring Cd levels in soil is essential to reduce its harmful effects on plants, people, and the environment. Increased concentrations of cadmium (Cd), like other stress factors, often result in symptoms of plant sensitivity and toxicity. One major effect of Cd toxicity in plants is that it stops roots from growing properly, which affects overall plant growth [10]. Cd also increases harmful molecules called reactive oxygen species, causing oxidative stress. This damages cell membranes, reduces the activity of protective enzymes, decreases plant size, and lowers crop quality [11]. The aim of this study is to examine the effects of cadmium (Cd), as a soil pollutant and heavy metal, on the seed performance, as well as morphological, physiological, and biochemical properties of *Vicia faba* in Koya-Kurdistan region, Iraq.

MATERIALS AND METHODS

2.1. Plant Materials and Field Experiment

The experiment was conducted on October 26, 2023, in the open field of the Biology Department, Faculty of Science and Health, Koya University, Kurdistan Region-Iraq, located at 36o N, 44o E and 570m of altitude above sea level. The experiment with randomized complete design (C.R.D) with three replications for each treatment. The study investigated the effects of cadmium chloride ($CdCl_2$) applied to soil at concentrations of four levels (0, 5, 25, and 50 $mg \cdot kg^{-1}$) on the growth of fava bean *(Vicia faba*). Each experimental unit consisted of 9 polyethylene bags for planting.

2.2. Preparation of cadmium concentrations and planting seeds

Cadmium chloride monohydrate ($CdCl_2 \cdot H_2O$, purity ≥ 99%, Thomas Baker, India) was used to induce stress was used to prepare the concentrations as 5, 25, and 50 $mg.kg^{-1}$.

Healthy legume seeds were purchased from the market in Koya city. The seeds were soaked in tap water at room temperature for 24 hours, following the method described by [12]. On October 26th, 2023, the seeds were planted at a depth of 2.5 cm in black polyethylene bags (10x10x30 cm), each filled with 3 kg of loamy soil. The soil was thoroughly mixed with the required concentrations of cadmium chloride ($CdCl_2$), denoted as Cd0, Cd15, Cd75, and Cd150, representing 0, 15, 75, and 150 $mg \cdot kg^{-1}$ of cadmium respectively. The bags were watered as needed with tap water to maintain uniform soil moisture (Figure 2.1).

Fig 2.1. Fava bean plants three months aged.

2.3 Meteorological Data

Table 2.1 shows the maximum and minimum temperatures, relative humidity, and rainfall amounts recorded during the growing season in the open field. These data were collected by the Agro-Meteorological Station in Koya

Table 2.1: Maximum and Minimum Temperature, Relative Humidity, and Rainfall During the Growing Season of Vicia faba.

Month (2023-2024)	Air Temp. C^o		Relative Humidity%		Rain fall (mm)
	Maximum	Minimum	Maximum	Minimum	
October	29.484	19.613	42.968	33.677	7
November	23.100	13.419	63.806	52.516	145.8
December	19.226	10.161	66.613	56.742	97.9
January	16.097	8.032	77.419	66.032	101.1
February	15.655	7.897	66.379	56.483	146.1

2.4. Studied Traits

2.4.1. Germination percentage (%) and velocity (Days)

[13] described seed germination (G) formula, as shown below:

$$G(\%) = \frac{L}{S} * 100$$

G (%) = Germination percentage
L = Total number of emerged seedlings
S = Number of planted seeds

[14] designed a formula of velocity of germination as following:

$$M(\text{days}) = \sum_{i=1}^{n} N_i G_i \,/\, \sum_{i=1}^{n} G_i$$

Where:
M: Velocity of germination (in days)
G: Number of seedlings that emerged on the observation day
N: Number of the days from sowing to the day of observation

The following parameters were measured for *V. faba* plants in February 2024, three months after seed germination:

2.4.2. Vegetative Growth

Plant height (cm), Number of leaves plant^{-1}, Stem diameter (cm), Length of main root (cm), Root diameter (cm), Fresh weight of shoot (g), Dry weight of shoot (g), Fresh weight of root (g), Dry weight of root (g), Shoot dry matter (%), Root dry matter (%), Number of nodules plant^{-1}, Fresh weight of nodules (g), Dry weight of nodules (g), Nodule dry matter (%), as described by [15]. Leaf area (cm^2) as described by [16].

2.4.3 Physiological and biochemical traits of Fava bean (*V. faba*):

3rd and 4th fully grown leaves were collected 97 days after seed germination to make the following estimations:

2.4.3.1 Estimation of Photosynthetic Pigment Content: The content of chlorophyll a, chlorophyll b, and total carotenoids (mg/g fresh weight) was estimated using the method described by [17].

2.4.3.2. Extraction and activity of enzymatic antioxidants: The extracts were prepared to analysis by [18].

2.4.3.2.1 Peroxidase (POD) Enzyme Activity ($\mu g \cdot g^{-1}$): The activity of the POD (peroxidase) enzyme was determined using the method described by [19].

2.4.3.2.2 Catalase (CAT) Enzyme Activity ($\mu g \cdot g^{-1}$)

The activity of the CAT (Catalase) enzyme was estimated using a UV-VIS spectrophotometer, following the method outlined by [20].

2.4.3.3 Extraction of non-enzymatic antioxidants:

2.4.3.3. **1 Ascorbic acid (AsA) content (gL^{-1}) as described by [21].**

2.4.3.3.2 Total Proline (TPr) Content ($\mu g \cdot ml^{-1}$)

The concentration of proline in fresh leaves was estimated using the method described by [22].

2.4.3.3.3 Total Carbohydrates (TCHO) (%)

The total carbohydrate content was determined as described by [23].

2.4.3.4 Determination of Stomata Traits

Stomata traits, including number of stomata, as well as length and width of the stomata, were determined following the method outlined by [24].

2.5 Statistical Analysis

The experiment was conducted using a completely randomized design (C.R.D), with cadmium (Cd) concentrations as the factor. Nine polyethylene bags were used as one experimental unit, with three replications for each treatment. Treatment means were compared using the analysis of variance (ANOVA), performed with statistical program SAS version 9.1. Duncan's multiple range test ($\alpha \leq 0.05$) was applied to compare the treatment means [25].

Results and Discussions

Effects of Cadmium on the Seed Performance, Vegetative Growth and Nodules of *Vicia faba*

The results of table 3.1 show that Cd application to the soil non - significant effects on seeds performance and some morphological traits of *V. faba*. Regarding vegetative growth and nodules, Cd application significantly increased plant height, stem diameter, plant leaf area, and the percentage of nodule dry matter at the 15 $mg \cdot kg^{-1}$ treatment compared to the control and other treatments. However, it had no significant effect on the number of plant leaves, root length, root diameter, or the percentage of the shoot and root dry matter. In contrast, the number of nodules per plant decreased with increasing Cd concentrations. The highest values for plant height, stem diameter, plant leaf area, and the percentage of the nodule dry matter were observed at the 15 $mg\cdot kg^{-1}$ Cd treatment (41.667 cm, 4.708 cm, 14.359 cm^2, and 9.597%, respectively), while the lowest values were recorded at the 150 $mg\cdot kg^{-1}$ Cd concentration (30.083 cm, 2.867 cm, 12.146 cm^2, and 5.597%, respectively). With regard to the nodules number of plants there were significant between all Cd treatments. The lowest values were observed in the 15, 75, and 150 $mg\cdot kg^{-1}$ treatments (27.00, 26.00, and 26.33), as shown in Table 3.1.

The results show that plants exposed to heavy metal (HM) stress had reduced growth compared to healthy plants. This decline is likely due to high heavy metal levels in the soil, which block nutrient absorption and stunt growth. Cadmium (Cd) is not needed for plant growth, and once absorbed, it can cause genetic, biochemical, and physiological changes that weaken plants. Root structure is important for water absorption, and Cd stress can damage roots, further affecting plant health [26]. The first line of defense against stress is the plant's cell walls and membranes, but once Cd builds up inside, it causes various toxic effects. This leads to the activation of complex biochemical pathways within the cell, along with the transcriptional regulation of Cd-responsive genes. These genes play a role in antioxidant defense mechanisms, metal tolerance, accumulation, transport, Cd binding for detoxification, and maintaining Cd cellular homeostasis [27]. As cadmium concentrations in the growth medium increase, its accumulation in the plant roots and shoots also rises. However, studies indicate that in lettuce plants, the Cd concentration in the roots is nearly twice as high as in the shoots [28]. Heavy metals require special attention due to their toxicity when exceeding natural levels, posing a serious threat to both plant and animal life. One of the major challenges for plant survival is pollutant absorption and metabolism from the environment. Plants absorb pollutants from the air and soil, playing a crucial role in air filtration by removing contaminants from industrial emissions. Additionally, plants serve as vital bio indicators of air quality [29]. These Findings align with previous studies, which also highlight the detrimental effects of Cd on plant physiology and its role in environmental pollution.
As shown in Figure 3.1, the nodules in *Vicia faba* were primarily distributed on the secondary roots. Rhizobia residing inside these nodules play a crucial role in nitrogen fixation, converting atmospheric nitrogen (N_2) into ammonia (NH_3), which serves as an essential nitrogen source for legumes. The observed increase in the percentage of nodule dry matter in *V. faba* may be attributed to the presence of certain rhizobial strains resistant to heavy metals, which can enhance plant growth even under heavy metal stress conditions. Rhizobial strains, such as Rhizobium leguminosarum bv *V.faba* exhibit high levels of resistance to heavy metals (e.g., Ni, Cd, Zn). These bacteria can protect themselves by pumping metal ions out of the cell, converting them to less toxic forms, and sequestering them inside the cell [30].

3.1. Effects of Cadmium on the Seed Performance, Vegetative Growth and Nodules of *V. faba*

Treatments	Germination		Plant Height (cm)	Stem diameter (cm)	Plant Leaves Number	Plant Leaf Area (cm^2)	Shoot Dry Matter (%)	Root Length (cm)	Root diameter (cm)	Root Dry Matter (%)	Plants Nodules Number	Nodules Dry Matter (%)
	Percent (%)	Velocity (Days)										
Cd 0	46.667 a	23.000 a	32.417 b	4.505 a	9.817 a	14.023 a	11.967 ab	19.083 ab	2.278 ab	10.883 b	42.500 a	5.917 b
Cd 15	53.333 a	26.167 a	41.667 a	4.708 a	11.867 a	14.359 a	13.127 a	20.667 a	2.980 a	16.500 a	27.000 b	9.597 a
Cd 75	49.333 a	24.567 a	36.333 ab	4.313 a	11.237 a	13.977 a	12.397 ab	17.667 ab	2.263 ab	13.503 ab	26.000 b	6.207 b
Cd 150	44.000 a	21.900 a	30.083 b	2.867 b	10.338 a	12.146 b	11.580 a	14.000 b	0.938 b	12.953 ab	26.333 b	5.597 b

* Values with the same letters in the columns are not significantly different at $p \leq 0.05$, based on Duncan's test. Different letters indicate
Significant differences

Fig 3.1 : The nodules statuse of V.faba species

3.2 Effect of Cadmium on some Physio-chemical components properties of *V. faba* leave3.2.1 Photosynthetic pigments

The results in Table 3.2 show that the effect of Cd was non-significant on some photosynthetic pigments in *V. faba*, including chlorophyll a and chlorophyll b. However, total carotenoids increased with the rising concentration of Cd at 15 $mg\cdot kg^{-1}$ compared to the control and other treatments. The highest value (41.667%) was observed at the 15 $mg\cdot kg^{-1}$ concentration, while the lowest value (30.083%) was recorded at the 150 $mg\cdot kg^{-1}$ treatment.

Carotenoids play a crucial role in enhancing plant resistance to various stressors. Their stable content under heavy metal exposure may be linked to their protective function. In contrast, chlorophyll appears to be more negatively affected by heavy metals than carotenoids [31]. Under Cd stress, chlorophyll biosynthesis is inhibited, leading to reduced chlorophyll content. This stress can also trigger protein degradation, hinder plant growth by promoting amino acid catabolism, and inhibit the activity of RuBisCO, a key enzyme in carbon fixation during the Calvin cycle. Cd interferes with two major CO_2 -fixing enzymes, RuBisCO and phosphoenolpyruvate carboxylase (PEPCase). Cd^{2+} ions can replace Mg^{2+} , an essential co-factor for carboxylation reactions, leading to structural damage and shifting RuBisCO activity towards oxygenation reactions. This can result in irreversible dissociation of RuBisCO's large and small subunits, completely inhibiting the enzyme. Additionally, Cd disrupts chloroplast function by affecting the oxidative side of Photosystem II (PSII), uncoupling electron transport. The primary mechanism of Cd toxicity in PSII is thought to involve the substitution of Ca^{2+} in the Ca/Mn cluster, which is crucial for oxygen evolution, or modifications in the Qb-binding site (plastokinone) within the chloroplast membrane [32]. These findings are further supported by [33].

Table 3.2. Effects of Cadmium mean of some photosynthesis pigments of V.faba species.

Treatments	Chl_a	Chl_b	TC
	mg /g fresh weight		
Cd 0	0.1977 a	0.1737 a	32.417 b
Cd 15	0.1843 a	0.1773 a	41.667 a
Cd 75	0.1553 a	0.1550 a	36.333 ab
Cd 150	0.1473 a	0.1487 a	30.083 b

* Values with the same letters in the columns are not significantly different at $p \leq 0.05$, based on Duncan's test. Different letters indicate significant differences.

3.2.1 Enzymatic antioxidants

Results in the table 3.3 indicate that the effect of Cd was significant on some enzymatic antioxidants such as CAT (Catalase) of *V. faba* fresh leaves. While it led to non – significant on the activity of POD (Peroxidase). The activity of CAT was significantly increased with rising Cd concentrations, reaching up to 150 $mg\cdot kg^{-1}$ $CdCl_2$ compared to the control in this studied species. The highest CAT activity (621.93 $\mu g\cdot g^{-1}$) was recorded at the 150 $mg\cdot kg^{-1}$ $CdCl_2$ concentration, while the lowest activity (271.43 $\mu g\cdot g^{-1}$) was observed in the control treatment of *V. faba*.

Cadmium (Cd) is a harmful pollutant for plants because it disrupts key biological processes like photosynthesis, carbohydrate production, and cell wall stability. These disruptions weaken the exchange of materials between the inside and outside of cells [34]. To protect themselves from damage caused by reactive oxygen species (ROS) and maintain growth, plants must balance ROS production and removal. This balance is controlled by enzymatic and non-enzymatic antioxidants. Too much ROS can be harmful, so plants activate their antioxidant systems to detoxify and restore balance. Higher antioxidant enzyme activity helps reduce oxidative damage and is linked to better stress tolerance. Under heavy metal stress, plants produce excess ROS, which can quickly damage DNA, RNA, proteins, and cell membranes through lipid peroxidation, leading to metabolic issues and even cell death [35]. These findings are also supported by [36].

3.2.3 Non- enzymatic antioxidants

As displayed in the table 3.3 results show that the effects of Cd was non - significant on all the non-enzymatic antioxidants such as AsA, TPr and TCHO of *V. faba* leaves.

Table 3.3: Effects of Cadmium on Some Enzymatic and Non-Enzymatic Antioxidants in V. faba Leaves.

Treatments	Enzymatic Antioxidants		Non-Enzymatic Antioxidants		
	Catalase ($\mu g g^{-1}$)	Peroxidase ($\mu g g^{-1}$)	Ascorbic Acid (gL^{-1})	Proline ($\mu g ml^{-1}$)	Total Carbohydrate (%)
Cd 0	271.43 b	123.83 a	7.844 a	9.1000 a	0.581 a
Cd 15	285.80 b	165.10 a	10.656 a	9.3767 a	0.859 a
Cd 75	342.90 b	225.67 a	8.844 a	9.4153 a	0.281 a
Cd 150	621.93 a	255.60 a	9.781 a	8.9270 a	0.588 a

* Values with the same letters in the columns are not significantly different at $p \leq 0.05$, based on Duncan's test. Different letters indicate significant differences.

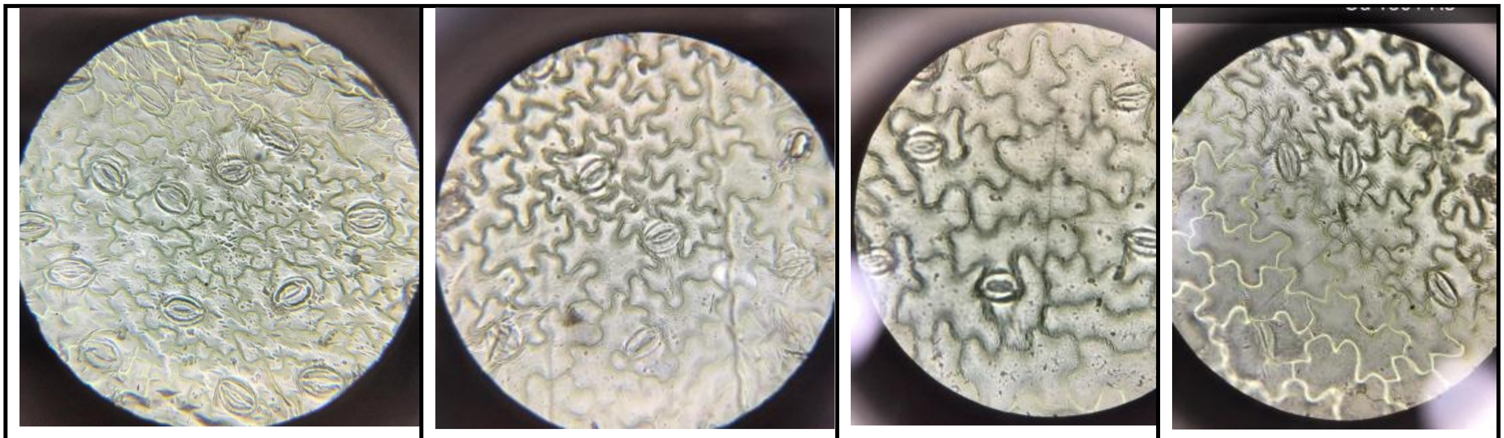
3.2.4 Some Stomata Traits

The results in Table 3.4 indicate that the effect of Cd was non-significant on all stomatal traits, including the number, length, and width of stomata on both the upper (adaxial) and lower (abaxial) surfaces of *V. faba* (Table 3.4; Figures 3.2 and 3.3). Except the width of the stomata on the adaxial surface was increased to (1.233 micron) at 150 $mg \cdot kg^{-1}$ as compared to (0.900 micron) at 15 $mg \cdot kg^{-1}$. Changes in the size and number of stomata are a manifestation of the plants' response to changes in the environment and are an important tool in regulating the absorption of pollutants by plants. Compared with guard cell length, stomatal density is relatively plastic and potentially adaptive to environmental changes. In addition, it causes stomatal closure due to entry of Cd into the guard cells in competition to Ca^{+2} . Decrease in stomatal density is also characteristic symptom of Cd stress resulting in lesser conductance to CO_2 which consequently leads to inhibition of photosynthesis. However, it is accepted that the factors limiting photosynthesis have stomatal and non-stomatal nature. Reduced photosynthetic activity is often due to iron deficiency in cadmium treated leaves. The changes in the stomatal density, size of stomata and epidermal cells as a response to environmental stress are important means of regulating the rate of absorption of risk elements by plants, while the stomatal index often remains unchanged [37].

Table 3.4: Effects of Cadmium on Some Stomata Traits of V. faba at 40x.

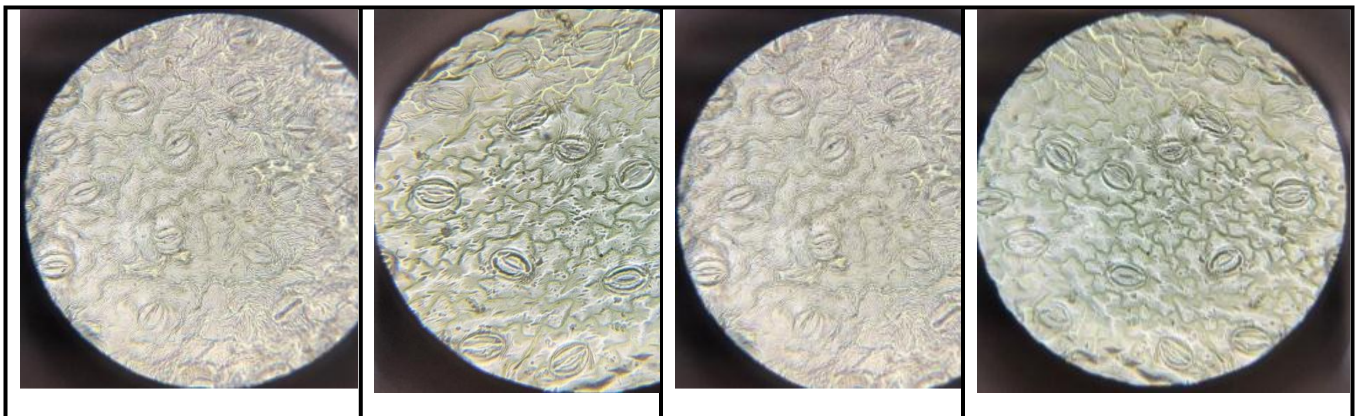
Treatments	Adaxial stomata			Abaxial stomata		
	Number	Length	Width	Number	Length	Width
			Micron			
Cd 0	7.667 a	1.700 a	1.066 ab	10.667 a	1.933 a	0.966 a
Cd 15	9.667 a	1.600 a	0.900 b	13.000 a	1.800 a	1.133 a
Cd 75	9.000 a	1.866 a	1.000 b	10.667 a	2.100 a	1.266 a
Cd 150	8.000 a	1.833 a	1.233 a	11.000 a	2.000 a	1.100 a

* Values with the same letters in the columns are not significantly different at $p \leq 0.05$, based on Duncan's test. Different letters indicate significant differences.



A	B	C	d

Fig 3.2. Stomata on the Upper (Adaxial) Leaf Surfaces of V. faba at 40x; (a. Cd0, b. Cd15, c. Cd75 and d. Cd150) mg.kg^{-1} soil.



A	B	C	d

Fig 3.3. Stomata on the Lower (Abaxial) Leaf Surfaces of V. faba at 40x ; (a. Cd0, b. Cd15, c. Cd75 and d. Cd150) mg.kg^{-1} soil

Conclusion

This study showed that soil contamination with cadmium (Cd) significantly increased certain morphological and biochemical properties of *V. faba*, including plant height, stem diameter, leaf area, the percentage of nodules dry matter, and total carotenoids at the 15 mg•kg^{-1} treatment. In contrast, the number of nodules decreased significantly with increasing cadmium concentrations. Furthermore, catalase (CAT) enzyme activity increased with higher cadmium concentrations, particularly at 150 mg•kg^{-1}. Effect of cadmium toxicity was non-significant on the seed performance, certain morphological traits, physiological traits and both enzymatic and non-enzymatic antioxidants.

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الاستجابات الفسيولوجية والكيميائية الحيوية لنبات (*Vicia faba L*) لإجهاد الكادميوم

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الخلاصة
أُجري هذا البحث في 26 أكتوبر 2023، في الحقل المفتوح التابع لقسم الأحياء، كلية العلوم والصحة، جامعة كوية، إقليم كردستان - العراق. صُممت التجربة وفق تصميم عشوائي كامل بثلاثة تكرارات. هدفت هذه الدراسة إلى بحث تأثير كلوريد الكادميوم (CdCl□) المُضاف إلى التربة بأربعة تراكيز (0، 5، 25 و 50) ملغم/كغم على أداء البذور، وخصائص النمو، والصفات الفيزيولوجية والكيميائية الحيوية للفول. أظهرت النتائج أن تلوث الكادميوم (Cd) لم يكن له تأثير معنوي على أداء البذور. ومع ذلك، انخفضت خصائص النمو الخضري، بما في ذلك طول النبات، وقطر الساق، ومساحة الورقة، ونسبة المادة الجافة في العقد الجذرية، مع زيادة تركيز الكادميوم. ومن المثير للاهتمام أن تركيزًا منخفضًا من الكادميوم (15 ملغم/كغم) حسّن النمو المورفولوجي بشكل طفيف، بينما أدى تركيز أعلى (150 ملغم/كغم) إلى انخفاض ملحوظ في هذه الصفات. كما انخفض عدد العُقيدات الجذرية لكل نبتة مع زيادة مستويات الكادميوم (15، 75، و150 ملغم/كغم) مقارنةً بالمجموعة الضابطة. في المقابل، لم يكن لتطبيق الكادميوم أي تأثير يُذكر على عدد الأوراق، أو طول الجذور، أو قطرها، أو المادة الجافة لكل من السيقان والجذور. أما فيما يتعلق بالصفات الفيزيولوجية والكيميائية الحيوية، فلم يكن لتلوث الكادميوم أي تأثير يُذكر على الكلوروفيل أ، أو الكلوروفيل ب، أو مستويات البيروكسيد، أو حمض الأسكوربيك، أو البرولين الكلي، أو الكربوهيدرات الكلية. ولم تُغير تركيزات الكادميوم بشكل ملحوظ محتوى الأوراق من أصباغ التمثيل الضوئي، أو نشاط بعض مضادات الأكسدة الإنزيمية وغير الإنزيمية. مع ذلك، ارتفع نشاط إنزيم الكاتالاز ومستويات الكاروتينات الكلية بشكل ملحوظ عند تركيز 15 ملغم/كغم مقارنةً بالمعاملات الأخرى. علاوة على ذلك، لم يكن للتعرض للكادميوم تأثير يُذكر على خصائص الثغور، بما في ذلك عددها وطولها وعرضها على السطحين العلوي والسفلي لنباتات الفول. تشير هذه النتائج إلى أنه في حين أن تركيزات الكادميوم المنخفضة قد يكون لها تأثيرات طفيفة أو مفيدة بشكل طفيف على بعض سمات النمو، فإن المستويات العالية من الكادميوم تؤثر سلبًا على معايير النمو والخصائص البيوكيميائية الرئيسية في الفول.

الكلمات المفتاحية: إجهاد الكادميوم، أداء البذور، الخصائص الفيزيائية والكيميائية، الفول.