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KINETIN-MEDIATED ALLEVIATION OF CADMIUM STRESS IN MUNG PLANTS: A COMPREHENSIVE ANALYSIS OF ANTIOXIDANT RESPONSE AND GROWTH ENHANCEMENT

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Abstract

Plants exposed to cadmium (Cd) stress have reduced growth, ineffective photosynthetic rate and poor ability to resist any other environmental calamity. In this study, we aimed to investigate the effect of Kn (kinetin) in alleviating Cd stress in mung plants. Plants of V. radiata were grown in soil contaminated with Cd (100 ppm Cd at 100 /Kg soil) for five days, and then Kn (10 µM) was aerially sprayed onto the leaves in a volume of 10 mL. The plants subjected to Cd stress alone had degraded growth conditions, with RGR, NAR, LAR and TPW reduced by 6.41 %, 59.22 %, 50 % and 6.20 % compared to the control. Interestingly, Kn, an application of synthetic cytokinin, improved growth conditions by 55 % in RGR, 30.12 % in NAR and 19.40 % in LAR and TPW 14 % compared to control. The underlying mechanism for growth enhancement by Kn was the induction of higher antioxidant activity. The Kn-treated seedlings had higher production of antioxidant enzymes such as peroxidase (POD) (50.87 %) and ascorbate peroxidase (APX) (32.61 %) and antioxidant secondary compounds such as TPC (59.21 %), TFC (26.35 %) and proline (28.07 %) compared to the control. This increase in antioxidant activities was due to the complementation of Kn with endogenous IAA (indole-3-acetic acid), GA4 (gibberellic acid) and tZ (trans-zeatin) in the seedlings as these were high in level (30.84 %, 19.21 %, and 35 % respectively) compared to the control. In contrast, these antioxidant activities were reduced in Cd

stressed seedlings compared to the control and therefore growth was severely suppressed. Hence, the mechanism of Kn to induce antioxidant activity was due to complementation with endogenous IAA, GA4 and tZ for higher antioxidant response and growth enhancement.

Introduction

Plant hormones or phytohormones are the minute signaling compounds that not only induce growth and development but enhance the plant resilience against several environmental stresses (Kumawat et al., 2023). These phytohormones are of two types such as natural hormones that are produced in the plants endogenously and synthetic hormones which are analogous to these hormones (Isoda et al., 2021). Kinetin (Kn), a synthetic cytokinin hormone, is known for its special capacity to regulate plant cellular division (Gauthier-Coles et al., 2019). These synthetic plant hormones have an important function in reducing heavy metal stress
(Emamverdian et al., 2021). When heavy metal stress affects plant development, Kinetin helps with resistance, detoxification, and growth (Khalil et al., 2021). Along with Kinetin, 6-benzylaminopurine (BAP or 6-BAP) and Thidiazuron (TDZ) both are synthetic cytokinins (Tashmatova et al., 2021). They, too, alleviate heavy metal stress by stimulating cell division and improving plant development, eventually assisting plants in combating heavy metal toxicity (Subrahmanyeswari et al., 2022). Furthermore, diphenylurea derivatives and Forchlorfenuron (CPPU), both members of the cytokinin family, contribute to improved plant tolerance to heavy metals, resulting in an association that improves plant health in contaminated conditions (Gul and Nawaz, 2023).

Similarly, IBA, a synthetic auxin hormone, affects the growth of roots and the intake of nutrients, which in turn help plants adapt to heavy metal-contaminated soils (Yadav et al., 2023). Gibberellins, which are well- known for their role in blooming and stem elongation, encourage overall plant development, strengthening the plant's resistance to heavy metal stress (Sytar et al., 2019). In short, each of these synthetic hormones has a specific function in enhancing plant vitality and resilience in confronting the effects of heavy metal problems, providing a diverse strategy for reducing the negative impacts of heavy metals on plant development (Kumawat et al., 2023).

Heavy metal stress negatively impacts crop yield and development, with elements such as lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg) and arsenic (As) being particularly toxic (Rahman et al., 2019). Some heavy metals such as copper (Cu), iron (Fe), zinc (Zn) and chromium (Cr III) play also an essential role in metabolic processes (Ghosh, 2020). Cadmium (Cd) is a major contaminant due to its efficient absorption and strong binding to enzymes and proteins with sulfhydryl groups (Wang et al., 2023). Phosphate fertilizers and municipal waste contribute to higher Cd levels in soil and hinder plant development by disrupting photosynthesis, leading to overproduction of reactive oxygen species (ROS) (Emamverdian et al., 2023). Plants utilize enzymatic and non- enzymatic antioxidants, particularly the ascorbate (AsA)-glutathione (GSH) cycle, to counteract oxidative stress caused by ROS (Hasanuzzaman et al., 2019). Thus, in short, antioxidant activity is highly required to detoxify the harmful effects caused by Cd (Zhou et al., 2022).

The ability of Kn to regulate plant stress tolerance to heavy metals is widely recognized (Begum et al., 2019). However, further studies are required to fully understand the mechanisms for induced antioxidation through interaction with other phytohormones. Sufficient evidence suggests that cytokinin appears to have a hormonal interaction with auxins and gibberellins to bring about optimal growth conditions in plants (Kurepa and Smalle, 2023). Therefore, the aim of this study was to investigate the influence of exogenously administered synthetic cytokinin such as kinetin on alleviating cadmium stress by inducing a resilience mechanism for effective growth of mung plants.

Methods and Materials

Plant materials and Treatment Conditions

Seeds of V. radiata (commonly known as Mung plant) were purchased from the Department of Agriculture in Khyber Pakhtunkhwa. To ensure their sterility, the seeds were subjected to a sterilization process as previously described (Yousaf et al., 2021). Germinated seedlings of uniform size were then produced and transplanted into soil contaminated with a 100 ppm Cd solution at a concentration of 100 mL/Kg of soil. Cadmium chloride (CdCl2) served as the cadmium source. Five days after transplantation, seedlings were exposed to a foliar spray containing 10 mL of a 10 µM kinetin (Kn) solution. The plants were then cultivated for another 21 days after hormone treatment. During this period, various growth measurements and biochemical kinetics data were recorded and analyzed.

Growth Kinetics

Seedling growth kinetics were studied using RGR (Relative Growth Rate), NAR (Net Assimilation Rate) and LAR (Leaf Area Ratio). RGR and NAR were calculated as mentioned (Yousaf et al., 2021). LAR was calculated by multiplying the total leaf area in cm2 by the total plant weight in grams (Yousaf et al., 2021).

Determination of enzymatic antioxidants Peroxidase (POD) and APX (Ascorbates peroxidase)

Fresh leaf sample (1 gm) was crushed with 10 mL of 1% polyvinylpyrrolidone in 1 g of potassium phosphate buffer (50 mM, pH 7.8) in a cold mortar and pestle. The homogenate was centrifuged at 15,000 * g for 20 min at 4 °C. POD and APX activity was observed after a crude enzyme extraction from supernatant (Lan et al., 2021).

To assess ascorbate peroxidase (APX) enzymatic activity, a reaction mixture was prepared consisting of 200 mL of leaf sample, 50 mM of sodium phosphate buffer (pH 7.0), 0.5 mM of ascorbic acid, and 0.1 mM of hydrogen peroxide (H2O2). Once the components were combined, the reaction mixture was allowed to incubate for 5 min. During this incubation period, the optical density (OD) of the solution was measured at a wavelength of 290 nm to determine the APX enzymatic activity (Mazrou et al., 2022).

Secondary Metabolite determination

The secondary metabolites included Total Phenolic content (TPC), Total Flavonoid content (TFC) and proline. Sample leaves were immediately frozen in the liquid nitrogen and then crushed into a fine powder. A soxhlet apparatus was used to keep the crushed powder (2 g) and 200 mL of

methanol for 36 h at room temperature. The extract was filtered after being concentrated under decreased pressure in a rotatory evaporator (Yousaf et al., 2019). The concentrated extract was used for analyses of TPC, TFC and proline.

Using the aluminum chloride (AlCl2) method, the total flavonoid content (TFC) of plant samples was estimated.

4.8 mL of 80 % methanol was added together with 500 µL of the supernatant, 100 µL of 10 % potassium acetate, and 100 µL of 10 % aluminum chloride. After that, the mixture was rapidly mixed and incubated in an agitator for 30 min. Following incubation, optical density was detected at 415 nm (Borah et al., 2022).

The Folin-Ciokaltou reagent test was used to quantify TPC (Merck KGaA, Darmstadt, Germany). Sample extract (1 mL) was diluted in 5 mL of methanol and then 500 µL of Folin-Ciokaltou reagent was mixed. After shaking the reaction mixture for 5 min, 1.5 mL of Na2CO3 (20 %) was added. The mixture was incubated for 2 h and then the absorbance was measured at 760 nm using a UV-vis spectrophotometer (Lambda 1050). The blank was made by mixing methanol with the same quantity of diluted extract (Pollini et al., 2021).

Proline was determined by adding a sample (1 mL) to 4 mL of 3 % sulfo-salicylic acid and centrifuging the mixture for 5 min. After that, the centrifuged liquid was agitated and then acidic ninhydrin reagent (2 mL) was added. Ninhydrin (1.25 gm) was heated in a mixture of 30 mL of pure glacial acetic acid and 20 mL of 6 µM phosphoric acid to create the ninhydrin reagent. The sample was heated for 1 h at 100 °C, and the resultant pellet was then poured into 4 mL of toluene. ODs were captured at 520 nm using a UV-vis spectrophotometer (Lambda 1050),

For TPC, TFC, and proline, the calibration curve were measured using 10, 50, 100, 200, and 300 mg/mL of gallic acid, quercetin, and, proline (Chavoushi et al., 2019).

Determination of Hydrogen Peroxide (H_2O_2)

A leaf sample weighing 1 g was ground into a powder in 10 mL of 0.1 % trichloroacetic acid (TCA) using a mortar and pestle, and the supernatant was obtained by centrifuging the mixture at 10,000 rpm for 20 min at 4

°C. The supernatant (1 mL) was mixed with 2 mL of KI (potassium iodide) (1M) and 1 mL of potassium phosphate buffer (pH 7.0). The mixture was incubated in the dark at room temperature for 45 min and the optical density (OD) was noted at 390 nm. A standard curve with known hydrogen peroxide concentrations (10 µmol/g, 100 µmol/g, and 500 µmol/g) was made to determine the quantity of hydrogen peroxide in the plant sample (Khan et al., 2021).

Determination of Malondialdehyde (MDA) .The leaf material (1 gram) was first ground into a fine powder using 5 mL of a 10 % trichloroacetic acid (TCA) solution. The resulting mixture was then subjected to centrifugation at 10,000 x g for 10 min. The reaction mixture was prepared by combining 2 mL of the supernatant with 2 mL of 10 % TCA and 0.6 % thiobarbituric acid. This mixture was then heated to 90°C for 40 min and subsequently cooled for 10 min in an ice bath. The optical density (OD) of the solution was measured at three different wavelengths: 450 nm, 532 nm, and 600 nm (Khan et al., 2021).

Phytohormones quantification

IAA(indole-3-acetic acid), GA4 (gibberellic acid) and tZ (Trans-Zeatin) were quantified as phytohormones, as described (Yousaf et al., 2022).

Statistical analysis

The statistical analysis was performed using SPSS software (version 16.0, SPSS Inc., Chicago, IL, USA). To assess the influence of Cd, Kn, and Cd-Kn on growth and biochemical kinetics, a full factorial analysis of variance (ANOVA) was employed. Significance was determined with a predefined significance threshold ($\alpha = 0.05$). Post-hoc comparisons for significance among different treatment conditions were conducted using Duncan's test.

Results and Discussion

After cultivating V. radiata seedlings in soil for a period of five days, they were subjected to various treatment conditions. These treatments included exposure to cadmium (Cd) stress at a concentration of 100 ppm (100 mL/Kg of soil) and the application of 10 mL of a Kn (Kinetin) solution at a concentration of 10 mM through foliar spraying. Additionally, a combination of both treatments, referred to as Cd-Kn, was also administered. Following a 21-day treatment period, the growth kinetics of the seedlings, encompassing Relative Growth Rate (RGR), Net Assimilation Rate (NAR), and Leaf Area Ratio (LAR), were meticulously assessed.

Under the influence of Cd stress, the growth kinetics exhibited notable declines: RGR decreased by 6.41 %, NAR reduced by 59.22 %, and LAR reduced by 50 % when compared to the control conditions, as depicted in Figure 1A, 1B, and 1C.

In contrast, the Kn treatment fostered an enhancement in these growth kinetics, with RGR, NAR and LAR increasing by 66 %, 51.29 %, 36.6 %, respectively as shown in Figure 1A, 1B, and 1C.

Surprisingly, the Cd-Kn treatment led to significant improvements in growth kinetics, revealing as a 55 % increase in RGR, a 30.12 % rise in NAR, and a 19.40 % boost in LAR when compared to the control group, as illustrated in Figure 1A, 1B, and 1C.

Furthermore, the assessment of Total Plant Weight (TPW) demonstrated that in the presence of Cd stress, the overall plant weight reduced by 6.20 %. However, the application of Kn resulted in a 14 % increase in TPW, while the Cd-Kn combination treatment led to a 4.56 % rise in TPW when contrasted with the control group, as depicted in Figure 1D.

Malondialdehyde (MDA) and H_2O_2 Level

Following exposure of V. radiata plants to Cd stress, the levels of hydrogen peroxide (H2O2) surged by 44.10

%, and malondialdehyde (MDA) increased by 30.81 %, as illustrated in Figure 2A and 2B. In contrast, the application of Kn treatment resulted in a substantial reduction of H2O2 by 53.98 % and a remarkable decrease in MDA by 89 % when compared to the control condition, as depicted in Figures 2A and 2B.

Intriguingly, the Cd-Kn combination treatment exhibited a notable decline in H2O2 levels by 42.80 % and a substantial decrease in MDA by 60.89 % compared to the control, as shown in Figure 2A and 2B.

Secondary metabolites

Plant secondary metabolites, such as proline, total flavonoid content (TFC), total phenolic content (TPC), and glycine betaine (GB), are known to be produced in response to stress conditions. When V. radiata plants were exposed to Cd stress, the levels of proline decreased by 32.82 %, TFC by 37 %, and TPC by 20.38 %, as depicted in Figure 3A, 3B, and 3C. Additionally, GB content showed a reduction of 53.8 % compared to the control (Figure 3D).

In contrast, when the mung plants were treated with Kn under Cd stress conditions, these decreases were effectively reversed, with proline levels increasing by 28.07 %, TFC by 26.35 %, and TPC by 59.21 %, as shown in Figure 3A, 3B, and 3C. Moreover, in the Cd-Kn treatment group, GB content exhibited a significant increase of 41 % when compared to the control, as demonstrated in Figure 3D.

Furthermore, Kn treatment on its own led to a notable increase in the production of these secondary metabolites, with proline, TFC, and TPC levels rising by 37 %, 32.89 %, and 78.51 %, respectively, as visualized in Figure 3A, 3B, and 3C. Additionally, GB content was significantly improved by 68.78 % compared to the control under Kn treatment, as shown in Figure 3D.

Phytohormones determination

The levels of growth-promoting phytohormones, including indole-3-acetic acid (IAA), gibberellic acid (GA4), and trans-zeatin (tZ), were assessed. In plants exposed to Cd stress, these phytohormone levels experienced a reduction, with IAA decreasing by 20 %, GA4 by 33 %, and tZ by 21.10 % when compared to the control, as visualized in Figure 4A, 4B, and 4C.

Conversely, the application of exogenous Kn (Kinetin) led to a significant increase in phytohormone levels, with IAA rising by 30.84 %, GA4 by 19.21 %, and tZ by 35 % when compared to the control, as illustrated in Figures 4A, 4B, and 4C.

Interestingly, under Cd-Kn treatment, a notable improvement was observed in the levels of these phytohormones, with IAA increasing by 18.20 %, GA4 by 15.82 %, and tZ by 24.65 % when compared to the control, as shown in Figure 4A, 4B, and 4C.

Enzymatic Activity

Cd stress had a pronounced effect on V. radiata, causing a significant decrease in peroxidase (POD) activity by

58.13 % and ascorbate peroxidase (APX) activity by 48.41% when compared to the control, as presented in Figure 5A and 5B. Conversely, the application of Kn (Kinetin) led to a remarkable increase in enzymatic activities, with POD activity surging by 50.87 % and APX activity by 32.61 % when compared to the control, as shown in Figure 5A and 5B. Likewise, under Cd-Kn treatment, there was a substantial improvement in these enzymatic activities, with POD activity increasing by 31.4 % and APX activity by 39.53 % when compared to the control, as depicted in Figure 5A and 5B.

Discussion

Cadmium (Cd) is an extremely non-essential and highly phytotoxic heavy metal, even at lower concentration (Bharti and Sharma, 2022). Heavy metals like Cd causes various harmful effects, including lipid peroxidation, disrupting bio-membranes, altering metabolism, and reducing the

uptake and translocation of essential nutrients and water, ultimately leading to reduced plant growth (Al-Khayri et al., 2023). The growth of V. radiata plants exposed to Cd stress was notably diminished when cultivated in soils containing 100 ppm Cd. To assess plant growth, parameters such as RGR (Relative Growth Rate), NAR (Net Assimilation Rate), LAR (Leaf Area Ratio), and TPW (Total Plant Weight) were used (Sharma et al., 2020). RGR measures the increase in dry matter (gm) per plant unit over a 24-h period (Gandhi et al., 2021). NAR indicates the efficiency of photosynthesis by relating the dry weight increase to the leaf area (Ghanbari and Technology, 2023). LAR represents the ratio of a plant's total leaf area to its total dry mass, and TPW signifies the mass of a plant or its components after drying, removing all water content (Shihan et al., 2020). Cadmium-stressed plants exhibited reduced RGR, NAR, LAR, and TPW, severely hampering the growth of V. radiata. Conversely, the application of Kinetin (Kn at 10 µM) increased these growth parameters. Phytohormones, small signaling molecules in plants, play a dual role in resisting environmental challenges and promoting growth and development (Tripathi et al., 2022). They can be either endogenous, naturally occurring in plants, or synthetic, hormone-analogous substances (Davies, 2010). Kinetin (Kn), a synthetic cytokinin, known for its ability to regulate growth in plants (Bozorova et al., 2022). These synthetic hormones are crucial in mitigating heavy metal stress, enhancing plant resistance, detoxification, and overall growth when heavy metals hinder these (Nguyen et al., 2021). For example, exogenous application of Kn reduces the vulnerability of Solanum melongena L. seedlings exposed to cadmium (Cd) (Verma et al., 2021). In another study, foliar Kn treatment was applied to pea plants growing in Cd-contaminated soil (25 µM) which accelerated their growth (Pandey et al., 2022). Similarly, in current research, Kn (10 µM) alleviated the toxic effects of Cd (100 ppm) by enhancing NAR, LAR, RGR, and TPW in **V. radiata.**

The application of Kn effectively alleviates the adverse effects of heavy metal stress on seedlings by boosting enzymatic and non-enzymatic antioxidant activities, resulting in an improved system for neutralizing reactive oxygen species (ROS), such as APX and POD leading to optimal growth conditions for plants (Hasanuzzaman et al., 2020). In V. radiata, Cd application reduced enzymatic activities like APX and POD leading to compromised growth, but interestingly, Kn application to Cd-stressed plants enhanced these activities, ultimately enhancing growth of V. radiata. The antioxidant activity of Kn is also demonstrated by mitigating the negative impacts of Cd stress on Datura innoxia plants through reducing hydrogen peroxide (H2O2) and malondialdehyde (MDA) levels in plants exposed to 50 and 100 mg Cd Kg-1 (Guenther, 1994).

The levels of malondialdehyde (MDA), a byproduct of cellular peroxidation of polyunsaturated fatty acids, and hydrogen peroxide (H2O2), a highly hazardous oxidant that induce high cell damage were observed at decreasing trend in V. radiata plants subjected to Cd stress. Notably, the decrease in MDA and H2O2 levels was more evident in the Kn and Cd-Kn treatment plants. The activated oxygen species have a tendency to undergo oxidation reactions with cellular macromolecules such as proteins, nucleic acids, and lipids (Juan et al., 2021). In order to reduce the buildup of reactive oxygen species (ROS), plants have evolved a complex antioxidative defense mechanism (Mansoor et al., 2022). A considerable proportion of secondary metabolites

including proline, total flavonoid content (TFC), glycine (GB), and total phenolic content (TPC), act as non- enzymatic antioxidant compounds produced by plants to enhance their competitive survival by coping with ROS under stress conditions (Sarker et al., 2018). In current studies, we noticed that the presence of these secondary metabolites in the plants of V. radiata subjected to Cd stress remained negligible in comparison to the control. However, the application of Kn treatment resulted in an increase in the synthesis of these metabolites in stressed plants of V. radiata. Similarly, the application of GB on plants under HM stress enhances photosynthesis, growth, antioxidant enzyme activity, nutrient absorption, and decreases oxidative
stress (Ali et al., 2020). For instance, the application of Kn in the plant Vicia faba resulted in a significant increase in GB levels (Shafiq et al., 2021). Furthermore, this increase of GB aids in the plant's ability to regulate water balance when subjected to heavy metal-induced stress (Yadav et al., 2020).

Usually all these defensive antioxidant activities to promote growth condition in plants is dependent on phytohormone interactions. Previous studies have shown that the presence of toxic metals in the environment leads to significant reduction in the levels of endogenous cytokinins, auxins, and gibberellins, in the green alga Acutodesmus obliquus (Piotrowska-Niczyporuk et al., 2020). The alleviation of heavy metal toxicity is achieved by exogenous cytokinins and auxins which regulate the levels of endogenous phytohormones such as endogenous auxins, gibberellins and cytokinin (Piotrowska-Niczyporuk et al., 2020). This advantage of use of synthetic hormones for stress alleviation is exploited in plant research in a wide range (Song et al., 2020). These synthetic hormones play a crucial role in modulating physiological and molecular responses in plants, particularly in their ability to withstand heavy metal stress, which is vital for their survival (Rahman et al., 2023). In similar context, we also exploited this scope by using Kn as a remedy to alleviate the Cd stress (100 ppm) in V. radiata. Intriguingly, Kn exogenous application exhibited a sharp resilience in the seedlings of V. radiata by enhancing the level of endogenous IAA and GA4 which alleviated Cd stress inducing antioxidant activity in the seedlings of V. radiata.

Conclusion

In conclusion, the study highlights the profound effects of cadmium (Cd) contamination on V. radiata (mung bean) plant growth, particularly by disrupting antioxidant mechanisms. However, the application of the synthetic cytokinin Kinetin (Kn) emerges as a promising remedy, enhancing the growth of seedlings by fortifying antioxidant defenses and stimulating the production of antioxidant secondary metabolites, such as TPC, TFC, and proline. Notably, Kn treatment was associated with increased enzymatic activities, including Peroxidase (POD) and Ascorbate Peroxidase (APX). This observed elevation in antioxidant activity was due to high level of endogenous indole-3-acetic acid (IAA) and trans-Zeatin (tZ) levels by Kn which further suggested that Kn played a pivotal role in mitigating the adverse impacts of Cd pollution, offering potential applications in promoting plant resilience to environmental stresses.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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Author Contributions

Conceptualization: Naveed Ali, Muhammad Junaid Yousaf; Formal analysis: Fawziah A. Al-Salmi, Amr Elkelish; funding acquisition: Siham M.AL-Balawi, Fawziah A. Al-Salmi; Investigation: Aisha Siddique, Fawad Ali; Methodology: Maha AlHarbi, Abdul Manan; Project administration: Imad Gul, Naveed Ali, Maha AlHarbi; Resource: Fawad Ali, Amr Elkelish, Fawziah A. Al-Salmi; Supervision: Imad Gul, Abdul Manan; Validation: Naveed Ali, Muhammad Junaid Yousaf, Maha AlHarbi; Visualization: Fawziah A. Al-Salmi, Amr Elkelish; Writing original draft: Fawad Ali, Siham M.AL-Balawi; Writing – review & editing: Naveed Ali

Disclosure Statement

No potential conflict of interest was reported by the author(s).

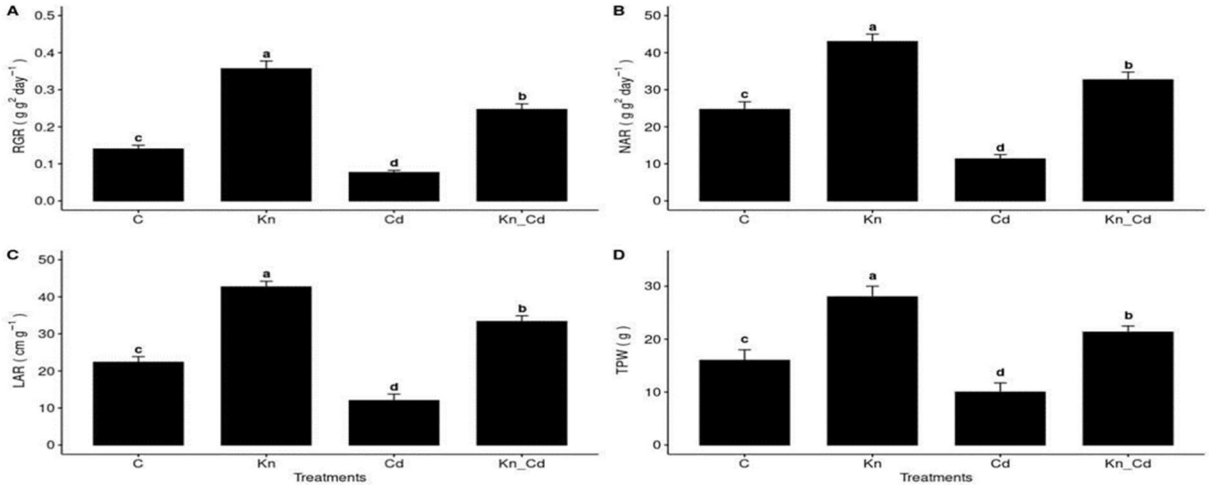

Figure 1

Identification of growth kinetics in plants of 21-day-old Mung plants following exposure to cadmium (Cd) stress (1800 ppm) or Kinetin (Kn) (10 µM), or both, including relative growth rate (A), net assimilation rate (B), leaf area ratio (C), and Total plant weight (TPW) (D).

Data are the average of three separate tests with standard error bars.

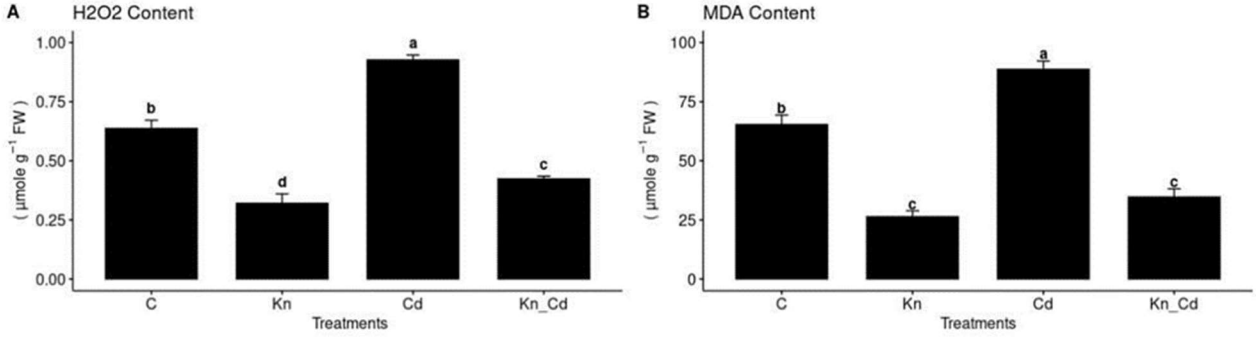

Figure 2

Evaluation of the levels of damage indicators such hydrogen peroxide (H2O2) and malondialdehyde (MDA), in 21-day-old Mung plants that have been subjected to cadmium (Cd) stress (1800 ppm) or Kinetin (Kn) (10 µM), or both.

Data are the average of three separate tests with standard error bars.

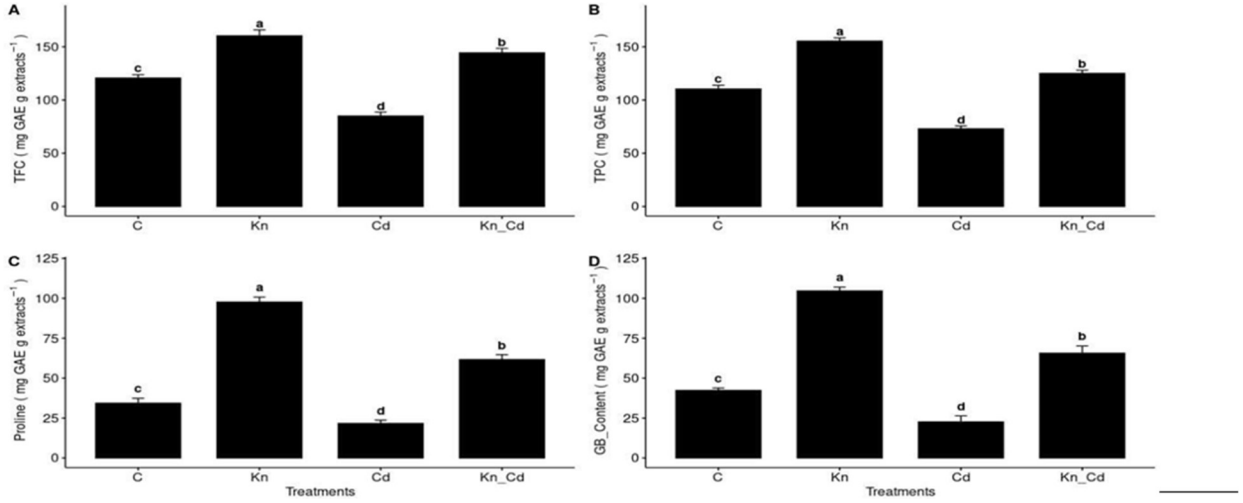

Figure 3

The 21-day-old Mung plants were subjected to cadmium (Cd) stress (1800 ppm) or Kinetin (Kn) (10 µM) stress, or both, to determine biochemical kinetics such as total phenolic content (TPC) (A), total flavonoid content (TFC) (B), proline (C), and Glycine betaine (GB) (D). Data are means with standard error bars from three separate experiments.

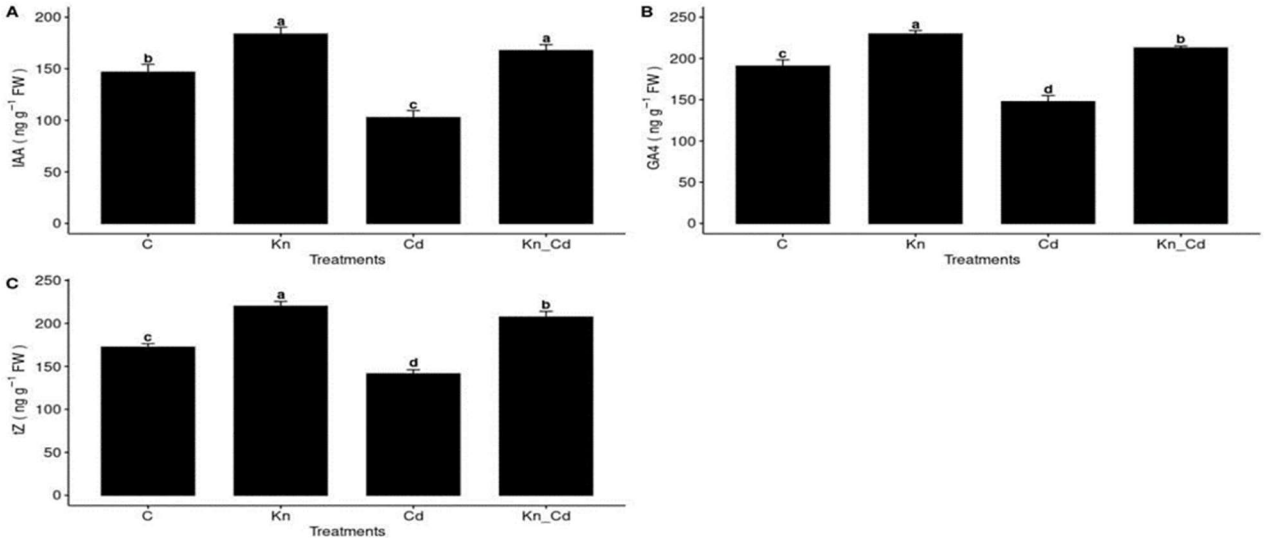

Figure 4

Identification of growth-promoting phytohormones in plants of 21-day-old Mung plants following exposure to cadmium (Cd) stress (1800 ppm) or kinetin (Kn) (10 µM), or both. Data are the average of three separate tests with standard error bars.

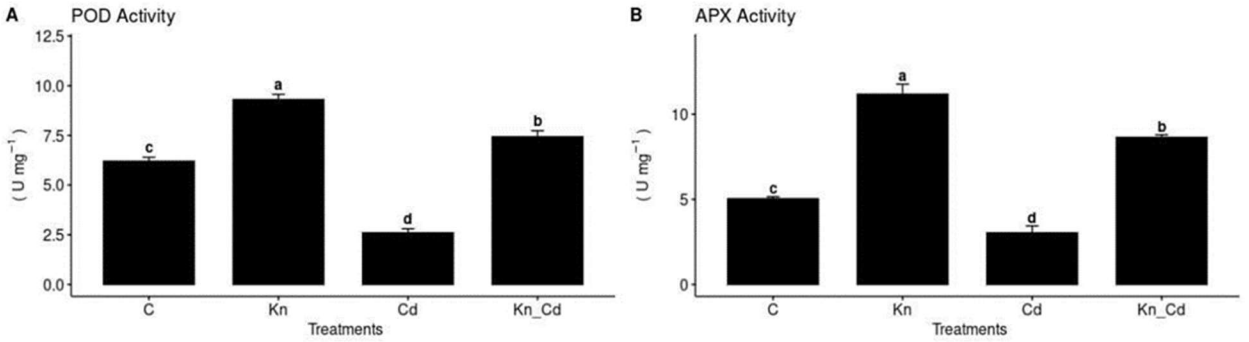

Figure 5

Superoxide Dismutase (POD) (A) and Ascorbate Peroxidase (APX) (B) activity was measured in 21-day-old Mung plants that had been subjected to either Kinetin (Kn) (10 µM) or cadmium (Cd) stress (1800 ppm) stress, or both. Data are means with standard error bars from three separate experiments.

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