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# Cadmium Stress in Wheat: Monitoring Changes in Biochemical Attributes

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**Abstract**

***Background and Objective*:** Cadmium (Cd), like all heavy metals, it causes drastic effects on the crops, especially wheat, the staple food of majority of populations worldwide. This study was designed to find out the effects of cadmium on the Biochemical Attributes of wheat fruit (*Triticum aestivum* L).

***Methodology*:** In a pot experiment, randomized design study cadmium was applied as cadmium sulphate ($CdSO_4$) at doses of 0, 5, 10, 25, and 50 mg $kg^{-1}$ soil. Healthy seeds (Seed Certified Department, Lahore) were soaked/sowed in clay-loamy soil (1:3 humus to soil ratio) in 15 kg of soil pots. Plantation of twelve seeds per pot for each of the three replications of each treatment, and subsequently pruned to six seedlings, totaling 90 plants, watered regularly. Following extraction with 80% acetone, biochemical and physiological characteristics, were examined spectrophotometrically, Infra-Red Gas Analyzer (IRGA) was used to assess photosynthetic rate, stomatal conductance, and transpiration. ANOVA and treatment compared using Duncan's Multiple Range Test were used to examine the results.

***Results*:** Cadmium exposure showed negative impact on physiological and biochemical parameters of wheat. Severe oxidative stress was indicated by a sharp drop in Chlorophyll *a* (79.17%) and *b* (2.44%) values. A 60% decrease in Chlorophyll concentration was observed from 3.22±1.09 ($T_0$) to 1.30±0.73 ($T_4$). Carotenoids showed a significant decline from 7.28±0.03 ($T_0$) to 2.09±0.06 ($T_4$). Chlorophyll *a* showed statistically significant sensitivity to cadmium stress compared to carotenoids and Chlorophyll *b*.

***Conclusion*:** The photosynthetic pigments in the wheat cultivar Sehar-06 are considerably and dose-dependently inhibited by cadmium stress.

**Keywords:** Cadmium, triticum, chlorophyll, photosynthesis, oxidative stress, plant leaves, soil pollutants.

## 1. INTRODUCTION

Long before during supernova explosions nuclear fusions in stars add up the heavy metals in the universe. These heavy metals become the part of our globe around 10-20 billion years ago [1]. As heavy metals are dangerous contaminants not only for the environment but also for the human beings. They cause lethal effects on human health. They enter human by consuming crops that are cultivated contaminated environments.

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Heavy metals pose cancer risk to humans. Contaminated soil can also contaminate the environment and human health by various exposure pathways that includes direst ingestion, inhalation and dermal contact [2].

Resurrection of cadmium in its elemental or compound forms destined different cycles. Compounds of cadmium comparatively shows minimal transduction while, elemental cadmium in either way (wet or dry) take up by the plants and become the part of food as salt or protein that linked to other compounds i.e., metallothionein [3]. Cadmium in high concentration shows direct and in direct effects on the human health. Atmospheric deposition, phosphate fertilizers, raw industrial and municipal effluents, mining waste incineration and sewage sludge are all the common agricultural practices, which are the

main sources of cadmium accumulation in agricultural soil [4].

Uptake of cadmium in plants is mostly through root. Toxicity of cadmium decreases the uptake as well as translocation of other essential elements by the plants. Uptake of cadmium by wheat (*Triticum aestivum* L.) mainly depends upon the soil contamination level, soil type and cultivar type, but uptake of cadmium by grain depends upon the shoot-to grain transfer as well as roots to grain through xylem and phloem loadings [5]. Roots absorbs the dissolved cadmium from the soil and become the main route of cadmium entrance in the plants, such absorbed cadmium from roots is transported easily to the shoots. This creates disorder in biochemical, physiological, morphology and growth of the plant.

Browning of roots and chlorosis depends upon the concentration of the cadmium. Another hazardous effect of cadmium is the accumulation of reactive oxygen species that ultimately disturbs metabolic functions in plants. Excess of cadmium cause chlorosis, leaf roll, wilting and growth retardation. Cadmium toxicity may also reduce gas exchange characteristics, photosynthesis, protein synthesis, membrane stability, transpiration rate and stomatal conductance in plants [6, 7].

Metal element accumulation in the crop grains is regulated by various physiological processes, including uptake from the soil medium, translocation from root-to-shoot and during maturation re-translocation into the grains.

Consumption of such contaminated grains becomes the main route for entrance of heavy metal in the human body [8]. National Food and Agricultural Organisation (FAO) and World Health Organisation (WHO) done weekly observations and provided provisional tolerable weekly intake (PWTI) for cadmium [3]. After rice and maize, wheat (*Triticum aestivum* L.) is the third most cultivated cereal crop worldwide, and its demand increases at alarming rate due to increase in population and consumption of its products worldwide [9]. But due to physiological and morphological disorders cause low wheat production. Wheat has more ability to accumulate and translocate the cadmium inside the plant body as compared to the other cereal crops that results in enhancing the cadmium accumulation in wheat grains. Hence products derived from wheat are the major source of cadmium intake by human being [5, 7, 10]. Many nutrients, including vitamin C and iron decline in cadmium presence. The immunity, deterioration of human function and may even cause disabilities related to malnutrition also appear [2]. Recent epidemiological studies revealed that cancers of vital organisations are linked to cadmium exposure. It may also trigger the mental-disorders that bring decline in cognitive and behavioural functions [11].

This study was designed to find out the effects of cadmium (*Triticum aestivum* L.) on growth of wheat, the staple food of Pakistani population. The main objectives

of this work was to study the effect of cadmium on the Biochemical Attributes of wheat fruit (*Triticum aestivum* L.).

## 2. METHODOLOGY

To study the effects of cadmium on the wheat plant v. Sehar-06, a complete randomized design was used. To conduct the research seeds of respective cultivar was collected from the "Seed Certified Department" (SCD), Lahore. From the collected sample healthier seeds were separated from the healthier seeds to ensure the best possible plant growth of wheat plants. Selected seeds were soaked overnight before sowing in the prepared soil to trigger the imbibition process in the seeds.

Research garden of Government College Women University, Sialkot was chosen to conduct the experiment with minimum external factors that may lead to the biased results of the experimental studies.

Pots were cleaned properly and their sides were lined with polythene bags to ensure the horizontal seepage of the metal salt must be blocked. 15 kg soil was filled in 15 pots. Best soil for growing plants i.e., Clay-loamy soil having ratio 1:3 of humus and soil was prepared in research garden of the university. Cadmium sulphate ($CdSO_4$) salt of measured quantity was added into the pots with varying quantity as per experimental design.

After filling the pots to fill up spaces and endurance of proper filling pots were waged manually. Overnight soaked seeds were sowed in pots. Distribution and seed sowing was planned as 12 healthy seeds were sown in each pot of the different treatments. 13 days later seed were sprouted and after thinning 6 seedlings were left for experimental studies in each pot. During the whole experimental period watering was done right according to the requirements through spray bottle.

Each treatment was run in triplets for better results and conclusions. In total 5 sets of triplets were made among them one set kept as control with no application of treatment of cadmium salt, while the other 4 sets were named as treatment 1 ($T_1$), treatment 2 ($T_2$), treatment 3 ($T_3$) and treatment 4 ($T_4$). Each set has defined amount of heavy metal salt treatment in them according to the pre-designed pattern. Numerical representation has given in Table **1** for better understanding.

Electrical weigh balance was used to ensure the proper and exact measurement of cadmium salt for each treatment to minimize the error in results. This has been done in research laboratory of the university.

**Table 1: Cadmium treatment and use of cadmium-sulfate salt.**

| Sr. # | Observational groups | Treatments of Cd (mg/kg) | Treatments (salt con. In mg/kg soil) |
|---|---|---|---|
| 1 | $T_0$ | Control | Control |
| 2 | $T_1$ | 5 | 141.75 |
| 3 | $T_2$ | 10 | 282 |
| 4 | $T_3$ | 25 | 708.75 |
| 5 | $T_4$ | 50 | 1417.5 |

In all the triplets each treatment in total has 18 plants, i.e., 6 plants per pot. Over all 90 plants were kept under observation for concluding the results by keenly investigate them.

Biochemical parameters were studied and observed closely to check the effect level of oxidative stress and its effectiveness on the photosynthetic machinery of the wheat plant.

For evaluating the chlorophyll, *a* and *b* content in wheat plant Predesigned formulas were used which are as;

- Chlorophyll '*a*' (mg/g) = [{(O.D.663x0.0127) - (O.D.645x0.00269)}x10x50]
- Chlorophyll '*b*' (mg/g) = [{(O.D.645x0.0229) - (O.D.663x0.00468)} x 10x50]
- Total Chlorophyll (mg/g) = [{(O.D.645x0.0202) -(O.D.663x0.00802)}x10x50]

Likewise for the carotenoids respective formula was considered for the numerical values of its level among all the treatments;

Carotenoid's content = [Vx383 x (As-Ab)]/(100xW)]

For preparing the samples to study the biochemical markers of wheat plants randomly selected fresh leaves were selected and made their paste by the help of pestle and mortar by adding few drops of acetone in it to aid in pasting them. In clean glass containers for each treatment 10ml of 80% acetone was added to dilute the leaves paste by filling up to the volume of 50ml in the flask and covered them preventing the acetone to evaporate. To stop the further reactivity of Chlorophyll content due to light exposure the containers were wrapped in aluminum foil and placed them in dark place in university research laboratory.

To measure the wavelength spectrophotometer was used to determine the carotenoids from the samples.

Infra-Red Gas Analyzer (IRGA) was considered and used to measure the physiological parameters of the prepared samples these parameters include; photosynthetic rate (A), stomatal conductance (Gs), and respiration rate.

For statistical analysis ANOVA i.e., Analysis of variance was used to determined and evaluate the different parameters that was concerned.

For simple stats working MS Office was used. For check out the probability Duncan's Multiple range test (DMR) was used.

## 3. RESULTS

Cadmium administration induced dose-dependent and significant stress not only on the physiological parameters but on the biochemical attributes of wheat plant.

In particular it effects photosynthetic machinery adversely that lead to the drastic downfall in the working rate of pigments. As remarkable decrease in the photosynthetic pigment was noticed with increase of cadmium dose to the wheat plant.

Trend in decline in the Chlorophyll *a* and *b* concentration remarkably proves the impact factor and severity of cadmium on photosynthetic pigments (Table **2**) more importantly on Chlorophyll *a* content as 79.17% ($p<1.33x10^{-13}$) caused by cadmium, while 2.44% ($p< 6.33x10^{-13}$) reduction in Chlorophyll *b* was noticed (Table **3**).

A progressive degradation in photosynthetic pigments caused by the cadmium across all the given treatments to the wheat plants, as in $T_1$, $T_2$ and $T_3$ gradual increase in effectiveness observed as downfall from $2.98 \pm 0.19$ ($T_1$), $2.11 \pm 0.06$ ($T_2$) and $1.90 \pm 1.25$ ($T_3$) with 7.45%, 34.47% and 40.99% reduction observed respectively that clearly defines the level of oxidative stress caused by cadmium on the reaction sites of photosynthetic machinery (Table **2**).

In case of shoot total Chlorophyll content declined by $3.22\pm 1.09$ ($T_0$) to $1.30\pm 0.73$ ($T_4$) (Table **4**) shows highest dose dependent stress caused by cadmium as in total 60% ($p< 1.68x10^{-11}$) reduction noticed in the photosynthesis rate, that proved Chlorophyll *a* which is the main and primary reaction centre pigment of photosynthetic machinery as more sensitive to the cadmium stress than Chlorophyll *b* comparatively.

**Table 2: Effect of cadmium on Chlorophyll *a* and *b*.**

| Treatments | Chlorophyll *a* | Chlorophyll *b* |
|---|---|---|
| **$T_0$** | 2.22 ± 1.09 | 2.28 ± 0.03 |
| **$T_1$** | 1.98 ±0.19 | 1.98 ± 1.33 |
| **$T_2$** | 1.11 ± 0.06 | 1.07 ± 0.32 |
| **$T_3$** | 0.90 ± 1.25 | 1.04 ± 0.19 |
| **$T_4$** | 0.30 ± 0.73 | 0.09 ± 0.06 |

As for the carotenoids, decrease of 7.28 ± 0.03 ($T_0$) to 2.09 ± 0.06 ($T_4$) (Table **4**) with 71.29% ($p < 2.17 \times 10^{-12}$) dose dependent reduction in T4 drags the attention towards the effect and severity level of cadmium of the carotenoids in wheat plant. In case of carotenoids least effective treatment among all the treatments was the $T_1$ with 6.98±1.33 (4.12%) reduction and its gradually increase as $T_2$ with 5.07 ± 0.32 (30.36%) reduction and $T_3$ with 4.04±0.19 (44.51%) reduction in the functionality observed (Table **5**).

**Table 4: Effect of cadmium on total chlorophyll and carotenoids.**

| Treatments | Total Chlorophyll | Carotenoids |
|---|---|---|
| $T_0$ | 3.22 ± 1.09 | 7.28 ± 0.03 |
| $T_1$ | 2.98 ±0.19 | 6.98 ± 1.33 |
| $T_2$ | 2.11 ± 0.06 | 5.07 ± 0.32 |
| $T_3$ | 1.90 ± 1.25 | 4.04 ± 0.19 |
| $T_4$ | 1.30 ± 0.73 | 2.09 ± 0.06 |

The severe and disproportionate decline in Chlorophyll *a* content in comparison to the other pigments in heavy metal toxicity often noticed as oxidative stress by cadmium primarily damages and dysfunction the most important and primary reactive site Chlorophyll *a* in wheat plants in comparison to the Chlorophyll *b* and carotenoids.

**Table 3: One way ANOVA for chlorophyll *a* and *b*.**

| ***Source of Variation*** | ***SS*** | ***df*** | ***MS*** | ***F*** | ***P-value*** | ***F crit*** |
|---|---|---|---|---|---|---|
| **Chlorophyll *a*** | | | | | | |
| Between Groups | 7.464626 | 4 | 1.866156 | 1341.676 | $1.33 \times 10^{-13}$ | 3.47805 |
| Within Groups | 0.013909 | 10 | 0.001391 | | | |
| Total | 7.478535 | 14 | | | | |
| **Chlorophyll *b*** | | | | | | |
| Between Groups | 8.961199 | 4 | 2.2403 | 1557.822 | $6.33 \times 10^{-14}$ | 3.47805 |
| Within Groups | 0.014381 | 10 | 0.001438 | | | |
| Total | 8.97558 | 14 | | | | |

**Table 5: One way ANOVA for total chlorophyll and carotenoid.**

| Source of variation | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| **Total Chlorophyll** | | | | | | |
| Between Groups | 7.464626 | 4 | 1.866156 | 508.0123 | $1.68 \times 10^{-11}$ | 3.47805 |
| Within Groups | 0.036734 | 10 | 0.003673 | | | |
| Total | 7.50136 | 14 | | | | |
| **Carotenoid** | | | | | | |
| Between Groups | 55.04443 | 4 | 13.76111 | 733.4943 | $2.71 \times 10^{-12}$ | 3.47805 |
| Within Groups | 0.18761 | 10 | 0.018761 | | | |
| Total | 55.23204 | 14 | | | | |

## 4. DISCUSION

For the photosynthesis a green pigment known as Chlorophyll is necessary, results obtained revealed that

treatment free plants have high and balanced volume of Chlorophyll a, Chlorophyll b, total Chlorophyll and carotenoids as well. Presence of these pigments in such plants that have cadmium in their soil show varying quantity. Remarkable reduction was noted which is due to the interference in Chlorophyll synthesis by toxic element as well as interruption in the magnesium uptake mechanism.

A study by [12], on a native plant (Elymus nutans Griseb.) of the Qinghai-Tibet Plateau showed that Chlorophyll contents under low concentration promotes growth, while high concentration inhibited growth under Cd treatment. The accumulation of Chlorophyll *a*, Chlorophyll *b* and Chlorophyll *ab* was decreased with the increase of Cd stress concentration.

In our study the Chlorophyll *a* and Chlorophyll *b* contents measured in leaves were decreased as cadmium increased in saline soil. Chlorophyll *a* decreases significantly in all wheat varieties under cadmium stress with varying levels. Different varieties showed prominent difference in Chlorophyll contents [13].

Generally, heavy metal first reaches the plant cell wall after being absorbed by plant roots [14], and then crosses the cell membrane to reach the cytoplasm. The heavy metals are then bound by chelates in the plant cytoplasm (such as amides, malic acid and other organic acids) to form nontoxic complexes, which are then transported to vacuoles for storage [15]. Proline, glutathione, protein and plant hormones are closely related to plant resistance to heavy metals, and are involved in regulating the physiological phenomenon of abnormal increase of plant ROS [16, 17]. To prevent heavy metal-induced ROS damage, plants rely primarily on metabolically mediated natural compounds such as phytochelin (PCs), reduced glutathione (GSH), carotenoids, and tocopherols, as well as enzymatic antioxidant systems, these include catalase (CAT), superoxide dismutase (SOD), ascorbate peroxidase (APX), peroxidase (POD), guaiacol peroxidase (GPX), etc. Increased levels of these metabolic intermediate compounds and antioxidant enzymes lead to increased stress tolerance to heavy metal induced ROS [18, 19]. MDA is an indicator of lipid membrane peroxidation intensity and damage degree of membrane system, and the larger the value is, the more serious the damage [20]. Chlorophyll a and Chlorophyll b contents measured in leaves which decreased as increase in cadmium in saline soil [21]. Chlorophyll a decrease significantly in all wheat varieties under cadmium stress with varying levels. Different varieties showed prominent difference in Chlorophyll contents [13].

## 5. CONCLUSION

The current study shows that the photosynthetic pigments of the wheat cultivar Sehar-06 are significantly and dose-dependently inhibited by cadmium stress. Chlorophyll *a*, *b*, total chlorophyll, and carotenoid contents were all markedly decreased by increasing cadmium doses,

suggesting a severe disturbance of the photosynthetic system. Chlorophyll an exhibited the biggest decrease of all the pigments, indicating that the principal reaction centers of photosynthesis are the primary targets of heavy metal toxicity and emphasizing its greater sensitivity to cadmium-induced oxidative stress.

The steady and statistically significant decreases seen in all treatments attest to the fact that soil cadmium buildup significantly hinders wheat plants' ability to perform biochemical processes. Overall, the results imply that high amounts of cadmium might significantly lower photosynthetic efficiency, which may eventually jeopardize plant growth and productivity.

## ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interests.

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## AUTHOR CONTRIBUTIONS

ML: Conceptualization, investigation, data curation and writing of the original draft.

AK: Conceptualization, methodology, resources, supervision and provision of project materials and tools.

ML and AK: Writing, review, editing and approval of the final version of the manuscript.

## REFERENCES

[1] Teschke R. Copper, iron, cadmium, and arsenic, all generated in the universe: elucidating their environmental impact risk on human health including clinical liver injury. Int J Mol Sci. 2024; 25(12): 6662. https://doi.org/10.3390/ijms25126662

[2] Huang Y, He C, Shen C, Guo J, Mubeen S, Yuan J, *et al*. Toxicity of cadmium and its health risks from leafy vegetable consumption. Food Funct. 2017; 8(4): 1373-401. https://doi.org/10.1039/C6FO01580H

[3] EL-Hengary SB, Abushofa FA, Azab AE. Cadmium toxicity: insight into sources, toxicokinetics, and effect on vital organs and embryos. J Clin Res Rep. 2023; 13(4): 1-10. https://doi.org/10.31579/2690-1919/319

[4] Zhou Z, Zhang B, Liu H, Liang X, Ma W, Shi Z, *et al*. Zinc effects on cadmium toxicity in two wheat varieties (Triticum aestivum L.) differing in grain cadmium accumulation. Ecotoxicol Environ Saf. 2019; 183: 109562. https://doi.org/10.1016/j.ecoenv.2019.109562

[5] ur Rehman MZ, Rizwan M, Hussain A, Saqib M, Ali S, Sohail MI, *et al*. Alleviation of cadmium (Cd) toxicity and minimizing its uptake in wheat (Triticum aestivum) by using organic carbon sources in Cd-spiked soil. Environ Pollut. 2018; 241: 557-65. https://doi.org/10.1016/j.envpol.2018.06.005

[6] Ahmad I, Akhtar MJ, Zahir ZA, Jamil A. Effect of cadmium on seed germination and seedling growth of four wheat (Triticum aestivum L.) cultivars. Pak J Bot. 2012; 44(5): 1569-74.

[7] Kabir AH, Rahman MM, Das U, Sarkar U, Roy NC, Reza MA, *et al*. Reduction of cadmium toxicity in wheat through plasma technology. PLoS One. 2019; 14(4): e0214509. https://doi.org/10.1371/journal.pone.0214509

[8] Rizwan M, Ali S, Abbas T, Zia-ur-Rehman M, Hannan F, Keller C, *et al*. Cadmium minimization in wheat: a critical review. Ecotoxicol Environ Saf. 2016; 130: 43-53. https://doi.org/10.1016/j.ecoenv.2016.04.001

[9] Gao X, Grant CA. Cadmium and zinc concentration in grain of durum wheat in relation to phosphorus fertilization, crop sequence and tillage management. Appl Environ Soil Sci. 2012; 2012(1): 817107. https://doi.org/10.1155/2012/817107

[10] Ci D, Jiang D, Dai T, Jing Q, Cao W. Effects of cadmium on plant growth and physiological traits in contrast wheat recombinant inbred lines differing in cadmium tolerance. Chemosphere. 2009; 77(11): 1620-5. https://doi.org/10.1016/j.chemosphere.2009.08.062

[11] Yang Y, Hassan MF, Ali W, Zou H, Liu Z, Ma Y. Effects of cadmium pollution on human health: a narrative review. Atmosphere. 2025; 16(2): 225. https://doi.org/10.3390/atmos16020225

[12] Hu Y, Wang H, Jia H, Peng M, Zhu T, Liu Y, *et al*. Effects of Cd treatment on morphology, Chlorophyll content and antioxidant enzyme activity of Elymus nutans Griseb., a native plant in Qinghai-Tibet Plateau. Plant Signal Behav.

2023; 18(1): 2187561. https://doi.org/10.1080/15592324.2023.2187561

[13] Perveen S, Shahbaz M, Iqbal M, Akram MS, Parveen A, Ali HM. Induction of cadmium stress tolerance in Triticum aestivum L. by alfalfa leaf extract. Appl Ecol Environ Res. 2016; 14(5): 121-36. https://doi.org/10.15666/aeer/1405_121136

[14] Zhang H, Heal K, Zhu X, Tigabu M, Xue Y, Zhou C. Tolerance and detoxification mechanisms to cadmium stress by hyperaccumulator Erigeron annuus include molecule synthesis in root exudate. Ecotoxicol Environ Saf. 2021; 219: 112359. https://doi.org/10.1016/j.ecoenv.2021.112359

[15] Viehweger K. How plants cope with heavy metals. Bot Stud. 2014; 55(1): 35. https://doi.org/10.1186/1999-3110-55-35

[16] Fryzova R, Pohanka M, Martinkova P, Cihlarova H, Brtnicky M, Hladky J, *et al*. Oxidative stress and heavy metals in plants. Rev Environ Contam Toxicol. 2017; 245: 129-56. https://doi.org/10.1007/398_2017_7

[17] Emamverdian A, Ding Y, Mokhberdoran F, Xie Y. Heavy metal stress and some mechanisms of plant defense response. Sci World J. 2015; 2015: 756120. https://doi.org/10.1155/2015/756120

[18] Riyazuddin R, Nisha N, Ejaz B, Khan MI, Kumar M, Ramteke PW, *et al*. A comprehensive review on the heavy metal toxicity and sequestration in plants. Biomolecules. 2021; 12(1): 43. https://doi.org/10.3390/biom12010043

[19] Sharma A, Kapoor D, Gautam S, Landi M, Kandhol N, Araniti F, *et al*. Heavy metal induced regulation of plant biology: recent insights. Physiol Plant. 2022; 174(3): e13688. https://doi.org/10.1111/ppl.13688

[20] Zhu T, Li L, Duan Q, Liu X, Chen M. Progress in our understanding of plant responses to the stress of heavy metal cadmium. Plant Signal Behav. 2021; 16(1): 1836884. https://doi.org/10.1080/15592324.2020.1836884

[21] Abbas T, Rizwan M, Ali S, Adrees M, Zia-ur-Rehman M, Qayyum MF, *et al*. Effect of biochar on alleviation of cadmium toxicity in wheat (Triticum aestivum L.) grown on Cd-contaminated saline soil. Environ Sci Pollut Res Int. 2018; 25(26): 25668-80. https://doi.org/10.1007/s11356-017-8987-4

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