Study of the Effect of pH on the Toxicity and Bioaccumulation of Cadmium on Beans [Phaseolus Vulgaris]

H. Benabid and M. F. Ghorab

***Abstract*—The behavior of many metallic trace metals is often affected by several factors, among them pH which plays a crucial role in the transport, distribution, uptake, solubility, bioavailability and bioaccumulation of ETM in plants from soils as reported by many authors. This study was conducted to elucidate the effect of pH on the toxicity of cadmium on beans (Phaseolus Vulgaris) with the main objective to reveal the response of bean plants at different pH values to different added concentrations of Cd^{2+}. The results revealed that the growth of beans increased with increasing pH. However, the uptake and the accumulation of cadmium decreased. Generally, it appears from the obtained results that the metals tested exert more toxic effect in acidic than in alkaline pH conditions.**

***Index Terms*—pH, solubility, bioavailability, absorption, toxicity.**

I. Introduction

Bioaccumulation of metals by plants depends on several biotic and abiotic factors such as pH, redox potential [Eh], the biological activity, the temperature, the solubilization, the insolubilization and the volatilization [1]-[3]. These factors affect the behavior of ETM not only in the plant system but in all the systems that constitute our environment. The decrease in pH which is considered as a determinant factor promotes the mobility of most metals by dissolving metal salts or the destruction of the retention phase [2]. It also influences the solubility and speciation of the metal and thus its toxicity as reported by [4]-[7]. PH has become a key variable in the bioavailability of Cd. However, liming may be insufficient to reduce the risk of contaminating the food chain by Cd. Several studies have enabled to elucidate the influence of pH on the bioavailability of trace elements particularly cadmium, through its effect on the soluble organic matter (OM), and the cation exchange capacity (CEC) to support the higher exchange sites likely to retain cations metal [8], [9]. The influence of pH on the behavior of cadmium has been widely reported in recent works such those undertaken by [10]-[12]. who worked on different species, but agreed on the fact that the pH greatly affects the toxic action of cadmium. The behavior of cadmium has been shown to be influenced by several parameters, among them the pH which has been shown by several researchers as a parameter affecting the solubility and the absorption of cadmium [13]-[15]. The influence of pH on the behavior of cadmium has been widely reported in recent works such as those made by [16] on green algae chlorella has shown signs of growth retardation at different pH acid values, [3.0-6.2] and alkaline pH [8.3-9.0] indicating that the optimal pH of normal growth was between 7.5 and 8.0. This could be explained by the respective actions of pH, namely the acidity that acts on the roots, reducing the absorption of the essential elements by plant creating a situation of deprivation as it is the case for creating an alkaline pH causing insolubility of essential nutrients for plant growth. From nowadays, it is becoming imperative to take into consideration the importance of this factor in any study of metallic trace metals [ETM] in all systems [17].

II. Method and Material

A. Plant Culture

Seeds of bean were grown in a hydroponic system for a period of 10 to 12 days, during which the plant reaches the` mature stage in terms of stem length and width of leaves. Plastic trays each containing 24 grains were used for the cultivation of plants that takes place in a culture chamber under the following conditions: temperature (20 ℃ ± 4 ℃), relative humidity (RH) (80%) and photoperiod of 16 hours light and 8 hours of darkness. The rate of humidity is maintained by jets of distilled water. After a culture period of up to 12 days, a uniform selection of plants is cleaned using al distilled water before being transferred into 100 ml flasks containing the nutrient solution to which is added the appropriate levels of cadmium for a period 7 days. Citrate solution is used to buffer pH (5.9 in this case) and small amounts of citric acid [C6O7H8: 0.01M] and sodium citrate [C6H5O7Na3.2H2O: 0.005M] are used to minimize possible effects of citrate on plants.

B. Plants Analysis

After a period of 07 days of culture in the nutrient solution, plants were collected, washed and cut into small pieces before being transferred to silica vats to be dried overnight at a temperature between 100 ℃ and 120 ℃. The samples, once dried in an oven at 60 ℃, were ground in silicate mortars, weighed and then transferred into 100 ml beakers prepared for mineralization is provided by `adding to a volume of 10 ml HNO_3 and heated on hot plate has an initial temperature between 70 ℃ and 90 ℃ which will be subsequently increased up to 120 ℃ -140 ℃. After 20 to 30 minutes of reaction time of mineralization, the samples are cooled and filtered before being analyzed by the atomic absorption spectroscopy [AAS].

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III. Results

All results are summarized in the followed figures.

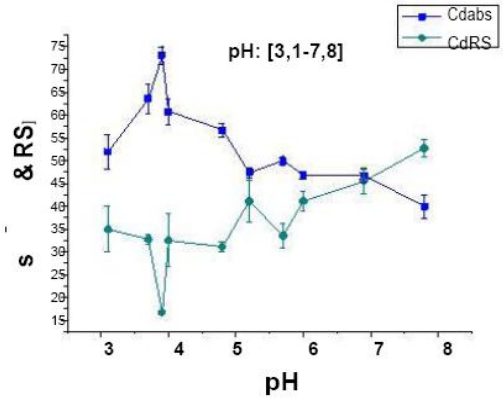

Fig. 1. Experiment carried out at fixed amount of Cd [100 µg total] and variable pH: [3.1 -7.8].

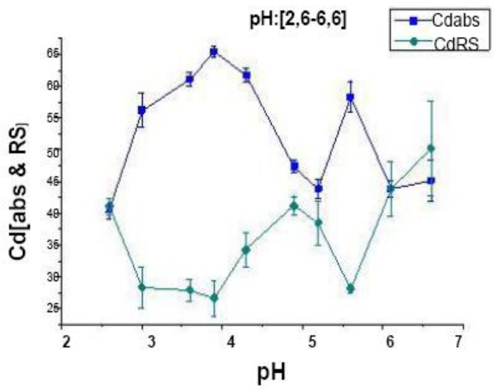

Fig. 2. Experiment carried out at fixed amount of Cd [100 µg total] and variable pH: [2.6-6.6].

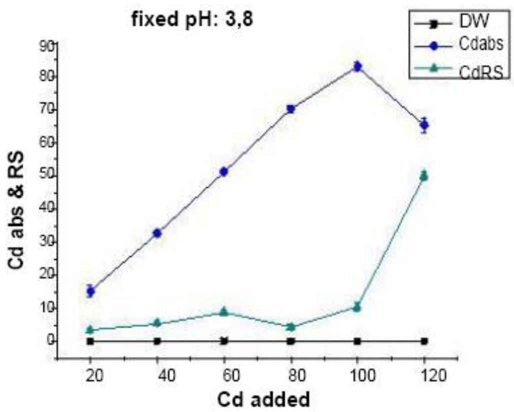

Fig. 3. Experiment carried out at fixed [pH: 3.8] and variable amounts of Cd [20 µg-120 µg].

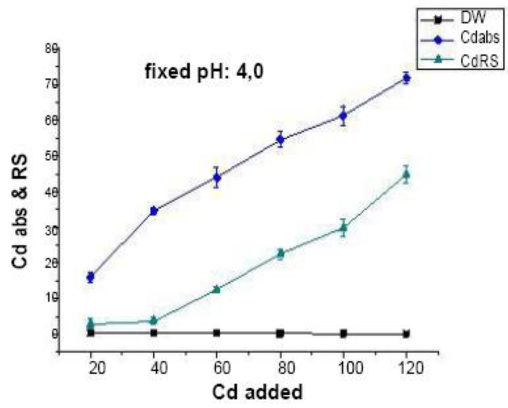

Fig. 4. Experiment carried out at fixed [pH: 4.0] and variable amounts of Cd [20 µg-120 µg].

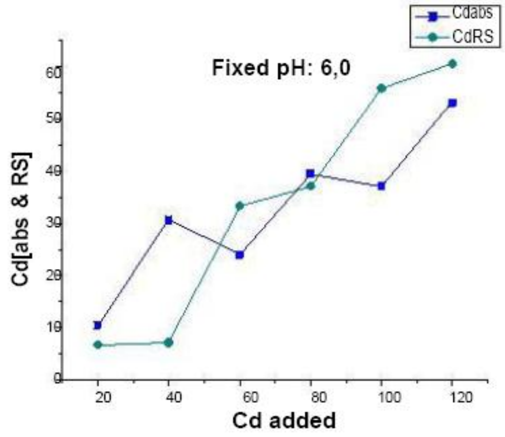

Fig. 5. Experiment carried out at fixed [pH: 6.0] and variable amounts of Cd [20 µg-120 µg].

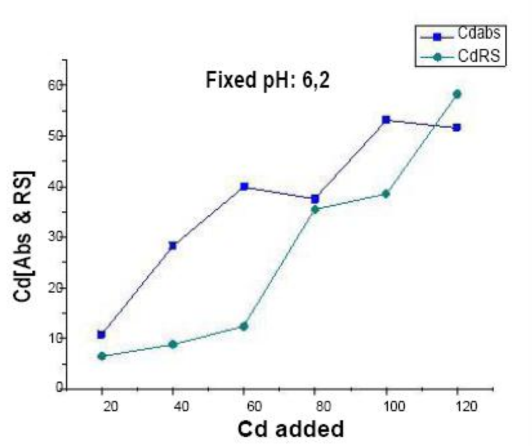

Fig. 6. Experiment carried out at fixed [pH: 6.2] and variable amounts of Cd [20 µg-120 µg].

IV. Discussions

Interesting comments were made as a result of experiments carried out to study the effect of pH on Cd uptake by plants. In all experiments, it was observed that at the two lowest pH levels 3.1 and 4.0, Cd uptake by plants and the total amounts of Cd per gram of dry weight for the same quantities of added Cd were significantly higher compared with plants grown in solutions at pH above 5.5. It was also observed that for the same high levels of added Cd (100, 120 and 140 µg total) and at lower pH values (3.1 and 4.0), plants have responded more quickly by showing the first symptoms due to the toxic effects of Cd. The first signs of Cd toxicity were observed on the third day of the experiment. A complete yellowing of leaves (chlorosis) was shown by plants grown in low pH solutions containing 100 µg of Cd and more. Necrosis was also observed in stems of all samples containing 60 µg of Cd and more. The general trend of results is still valid for all experiments in terms of effects on the performance and the efficiency of the pH on Cd uptake by plants. From the results obtained, it became clear that the amounts of Cd absorbed by bean plants were higher at pH3.8 and pH 4.0 than at pH 6.0, which could be an indication that the optimum pH is between 3.0 and 4.0. The highest amount of Cd remaining in the nutrient solution was obtained for the highest pH values: 6.0, 6.9 and 7.8. It was also observed that at a high values pH, the

Cd uptake by plants is lower and the appearance of symptoms of toxicity of Cd was delayed for plants treated with high levels of cadmium. Given the composition of the nutrient solution used, there is a possibility of the formation of Cd-phosphate salt which can retain Cd in solution. The reaction of equilibrium would have the following form as suggested by Street *et al.* (1978).

$$Cd_3\,(PO_4)_2 + 4H^+ \longrightarrow 3Cd^{2+} + 2H_2PO_4^-$$

From this reaction we can predict the formation of an insoluble salt Cd3 $(PO4)_2$, observation strengthened through four additional experiments that we have conducted using cadmium as Cd $(NO_3)_2.4H_2O$. An amount of 180 µg Cd total was added to 5 standard samples at different values of pH [3.4, 4.5, 6.5, 7.3 and 8.2]. After an hour, we observed the appearance of a gray-whitish precipitate in samples at pH 6.5, 7.3, and 8.2 as shown in the table below. The other samples remained bright and clear even after a period of 07 days. And these are the pH values we have used for all experiments of the current work. The pH range of the solution was maintained at about 5 to 6 considered to be adequate for the growth of several species. Cd was added as [Cd $(NO_3)_2$] and its addition was carried out at a range of 0 µg to 200 µg.

TABLE I: [CD] ADDED: 180 µG TOTAL

pH	µg Cd [solution]	µgCd [filtre]
3.3	171.37	4.11
4.5	160.95	12.85
6.5	106.42	67.44
7.3	52.77	117.62
8.2	37.24	131.23

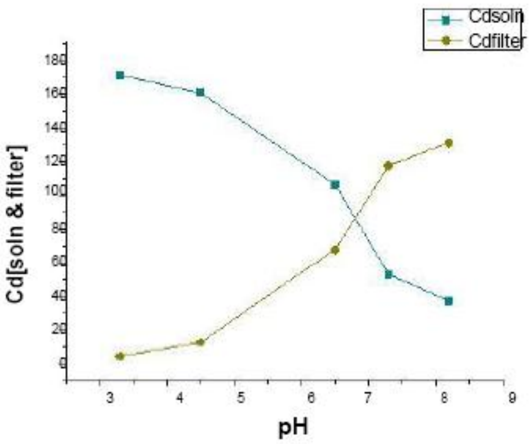

Fig. 7. Experiments conducted using fixed amount [180 µg total] of Cd as Cd(NO3)2.4H2O and variable pH values [3.4, 4.5, 6.5, 7.3 and 8.2].

V. CONCLUSION AND PERSPECTIVES

From all the experiments we have carried out and from the results obtained, we found that pH decreases the solubility and bioavailability of Cd in plants possibly by forming an insoluble compound such for example; $Cd_3\,[PO_4]_2$.

The most appropriate chemical explanation for the formation of the precipitate would be a comprehensive study to determine the solubility product of the phosphate compound of cadmium. The pH has become a key variable to determine the bioavailability and the transport of metallic trace metals [ETM] and especially Cd within different systems of the environment. Knowing that nowadays liming is becoming insufficient to reduce the risk of contaminating the food chain by Cd, intensive studies are needed to allow a better approach to elucidate the influence of pH on the bioavailability of trace elements , especially that many trace metals are widely used in food that we are consuming.

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