PHYTOEXTRACTION OF CADMIUM BY BEANS AND SWEET POTATOES FROM SOILS

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ABSTRACT

The distribution of cadmium in different parts of beans and sweet potatoes plants was investigated after the process of phytoextraction. Cadmium which is extremely toxic in relatively low concentrations is highly mobile in the soil-plant system and enters into the food chain easily, where it may provoke both human diseases and well known toxicity effects on animals, microorganisms and plants. Field experiments were carried out with two crops: beans and sweet potato. They were planted in soils contaminated with different cadmium concentrations and in an uncontaminated soil to determine the extent of absorption of cadmium by *Phaseoulus vulgaris* (beans) and *Ipomoea batatas L* (sweet potatoes) in soils. Results showed that cadmium absorption by the two plants increased with an increase in the concentration of added cadmium. Within beans and sweet potatoes plants, the maximum Cd content was found in the leaves (43.32 mg kg^{-1} for sweet potatoes and 34.75 mg $kg^{-1}$for beans). Sweet potatoes had the highest cadmium absorption capacity compared to beans. The cadmium contents in the edible roots of all two plants exceeded the allowable quantities stipulated by various nations (maximum absorption values of 34.16 mg kg^{-1} for sweet potatoes and 32.05 mg kg^{-1} for beans). The extent of absorption of cadmium by sweet potatoes and beans plants was compared and the extent to which cadmium can be dangerous to the health if beans and sweet potatoes planted on a soil contaminated with cadmium are consumed was evaluated and some recommendation made on the type of soils good for planting of beans and sweet potatoes. Thus, it can be concluded from the results obtained that plants growing in cadmium-contaminated soils should be banned as foodstuff and soils with slight cadmium contamination should not be used for growing sweet potato, beans and any other food crop.

Keywords: *Sweet potatoes, beans, heavy metal, phytoextraction, accumulation.*

1. INTRODUCTION

The increasing use of wide varieties of heavy metals in industries nowadays has caused serious problems in environmental pollution [1]. This pollution which is linked to industrial and agricultural development constitutes a very serious problem due to the expansion of industries which discharge into the environment dangerous chemicals detrimental to the health of human beings. Also, both treated and partially treated industrial wastewaters and solid wastes discharged into the environment are major causes of soil contamination by heavy metals [2]. By contaminating the food chain, these elements pose a risk to the environment and human health [3]. The problem of farmland contamination by heavy metals has raised serious concerns for emerging countries such as Cameroon. The contaminants accumulated in the plants not only affect the growth and quality of crops but also threaten the health of consumers [2]. Heavy metals are generally defined based on their specific properties (high molecular weight, specific gravity greater than 5 g cm^{-3} and the capacity to form polyvalent cations). The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, and Zn. Some of these metals such as Zn, Cu, Mn, Ni, and Co are micronutrients necessary for plant growth, while others such as Cd, Pb, and Hg have no biological functions [4]. Among these, Cd and Pb are the most dangerous metals for human health. They have become a major cause of illness, aging and even genetic imperfections [5]. Geological and anthropogenic activities are sources of heavy metal contamination in soils [6]. Other sources can include unsafe or excess application of pesticides, fungicides and fertilizers [7]. Interestingly, small amounts of some of these elements are common in our environment and diet and are actually necessary for good health. Iron, for example, prevents anaemia. Some of these metals can become toxic when they exceed the norms [8]. This is the case of copper (Cu), nickel (Ni), zinc (Zn) and Iron (Fe). Metal pollution has harmful effects on biological systems and does not undergo biodegradation. Toxic heavy metals such as Pb, Co, and Cd can be differentiated from other pollutants, since they cannot be biodegraded but can be accumulated in living organisms, thus causing various diseases and disorders even in relatively lower concentrations [9].

Cadmium is assimilated readily by plants and it is absorbed by aquatic organisms in its free form Cd^{2+} and increased salinity has been found to reduce its bioaccumulation. Cadmium is used in the manufacture of nickel-cadmium batteries, PVC plastics, and paint pigments [10]. Atmospheric pollution, phosphate fertilizers and sewage sludge seem to be the major sources of cadmium deposition in agricultural soils. Cadmium is one of the principal heavy metals responsible for kidney damage, renal disorder, high blood pressure, bone fraction and destruction of red blood cells [11]. Symptoms of acute cadmium exposure are nausea, vomiting, abdominal pain, and breathing difficulty. Chronic exposure to cadmium can result in chronic obstructive lung disease, renal disease, and fragile bones. Today, cadmium is classified as a group I human carcinogen, as sufficient evidence for carcinogenesis has been found in both animals and humans [12]. Phytoremediation in general implies the use of plants (in combination with their associated microorganisms) to remove, degrade, or stabilize contaminants [13]. It is defined as an emerging technology, using selected plants to clean up the contaminated environment from hazardous contaminants to improve environmental quality. Phytoextraction is seen as an alternative green solution to the soil pollution problem. Plants used for phytoextraction must be fast growing and have the ability to accumulate large quantities of environmentally important metal contaminants in their shoot tissue [3]. Several researchers have screened fast-growing, high-biomass accumulating plants, including agronomic crops, for their ability to tolerate and accumulate metals in their shoots. The major factors governing cadmium speciation, absorption and distribution in soils are pH, soluble organic matter content, hydrous metal oxide content, clay content and presence, type of organic and inorganic ligands, and competition from other metal ions [3]. As soon as the soil pH decreases, the transfer mobility and the accumulation of Cd are favored. Plants take up small amounts of heavy metal compounds together with essential nutrients and can translocate them through their various organs and tissues to the food chain [14]. In general, different plant parts contain different heavy metal quantities, the highest ones being contained in roots and leaves, and the smallest in flower buds, fruits, tuber and seeds [15].

Cameroon as an emerging country relies much on agriculture which is the backbone of the economies of most countries in the world. For soil to produce crops successfully, it must not just have an adequate supply of all necessary nutrients that plants need but must also be totally free from toxic heavy metals such as cadmium. Due to the fact that most farmers in Cameroon use fertilizers (which are sources of cadmium) to improve on their agricultural yields; it is therefore important to test the soil in order to ensure not only high productivity but its quality as well. Therefore, evaluating the possibility and extent of absorption of cadmium by *Phaseoulus vulgaris* (beans) and *Ipomoea batatas* (sweet potatoes) in soils was the objective of this research.

2. MATERIALS AND METHODS

The experiment was carried out at the Faculty of Agronomy and Agricultural Science (FAAS), University of Dschang, Cameroon in May 2015 during the rainy season on a soil precharacterised for physico-chemical variables using standard methods [16]. The selected plants were sowed in cadmium–contaminated soils and uncontaminated soils. Contaminated soils were synthesized by preparing Cadmium solutions which were later sprayed on the soils. The soils were labelled A1, A2, A3, A4, A5 and A6 representing 80 ppm, 60 ppm, 40 ppm, 20 ppm, 10 ppm and 0 ppm (control) of Cd in the soil samples respectively. The control soil sample was analysed for the assessment of pre-existing Cadmium prior to sowing. Crops were grown (soil tilling, seed sowing, weeding and mulching) under standard agronomic conditions on experimental plots made up of six tyres and harvested at maturity after three months. The heavy metal content was determined in the morphological organs (leaves, stems and fruits) of the investigated crops: beans and sweet potatoes. After drying at 105 °C and grinding, 1 g of the dry sample was burnt at 450°C for 2 hours. The resulting ash was digested with HNO_3 (0.5 M solution) at room temperature. The mixture was filtered and the filtrate subjected to atomic absorption spectrometric (AAS) analysis for cadmium content. The results were statistically evaluated as follows: The student's t-test was used to compare Cd absorbed by the fruit, leaves and stems of both plants. Also correlation analyses were performed to find out any relationship that exists in Cd content between the different plant parts studied. Student test and correlation analyses were performed using SPSS version 19 (at 95% confidence interval).

3. RESULTS

Results of physico-chemical analysis showed that the soil is classified as ferralitic (clay texture according to the texture triangle classification), having a pH-H_2O = 5.8, pH-KCl = 5.6, organic carbon =1.52% and a high CEC value of 31.2 mg kg^{-1}. The initial soil contained 3.00 mg $kg^{-1}$of exchangeable Cd. The availability of certain heavy metals in soils depend on the physico-chemical properties of the soil such as soil pH, cation exchange capacity (CEC), and organic matter (OM)). One of the most valuable pieces of information one can get from soil testing is a measure of soil acidity. Soil pH is an indicator of the soil's acidity which is a primary factor controlling nutrient availability, microbial processes, and plant growth [17, 18]. The soil was acidic with a pH value of 5.8. This pH value is suitable for the growing of sweet potatoes and beans. This is in line with findings of Beerneat and Bitondo (1993) [19] who showed that sweet potatoes and beans grow generally in a soil with a pH range from ('4.5 -7.5 and 5.2-8.3) respectively. The quantity of cadmium absorbed is presented in Table 1 and Table 2 below for sweet potatoes and beans respectively while Figure 1 and Figure 2 present the distribution of cadmium among different parts of sweet potatoes and beans respectively.

Table 1: Results of cadmium concentration (mg kg^{-1}) absorbed by *Ipomea batatas L.*

Plant part	Control (A_6)	A_5	A_4	A_3	A_2	A_1
Fruits(edible roots)	0.12	2.00	4.50	5.9	15.15	34.16
Leaves	1.15	6.64	10.00	15.15	39.80	43.32
Stems	0.15	5.50	7.40	8.40	19.37	34.87

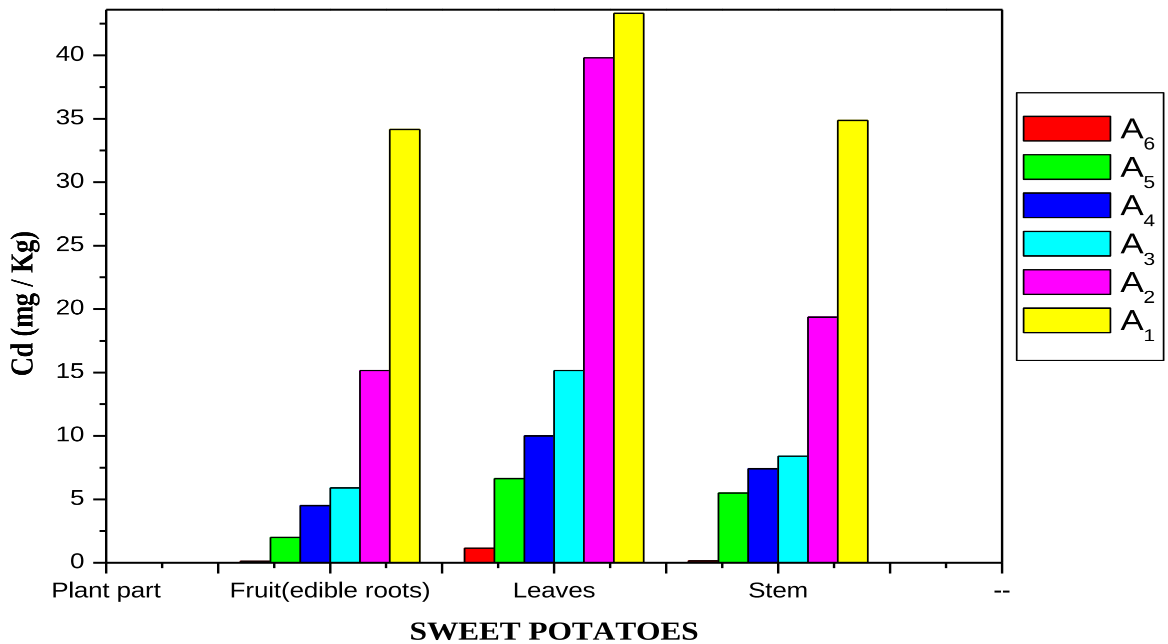


Figure 1: Cadmium distribution among organs of sweet potatoes (mg / Kg)

Table 2: Results of cadmium concentration (mg kg^{-1}) absorbed by *Phaseoulus vulgaris*

Plant part	Control(A_6)	A_5	A_4	A_3	A_2	A_1
Grains(fruits)	0.06	0.25	3.00	4.93	10.06	32.05
Leaves	0.20	4.93	5.63	15.15	20.08	34.75
Stems	0.13	2.67	4.80	12.33	15.15	32.75

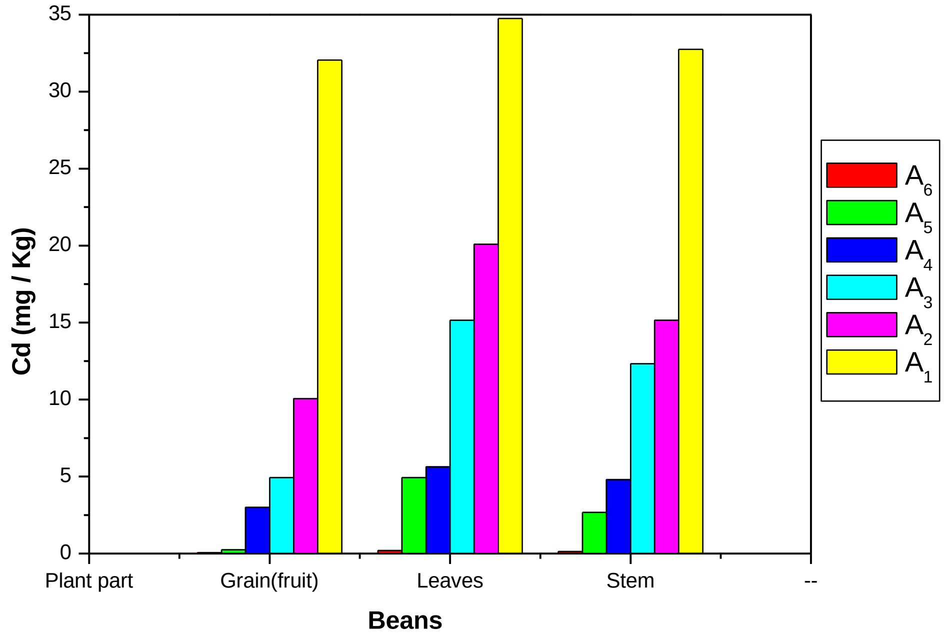
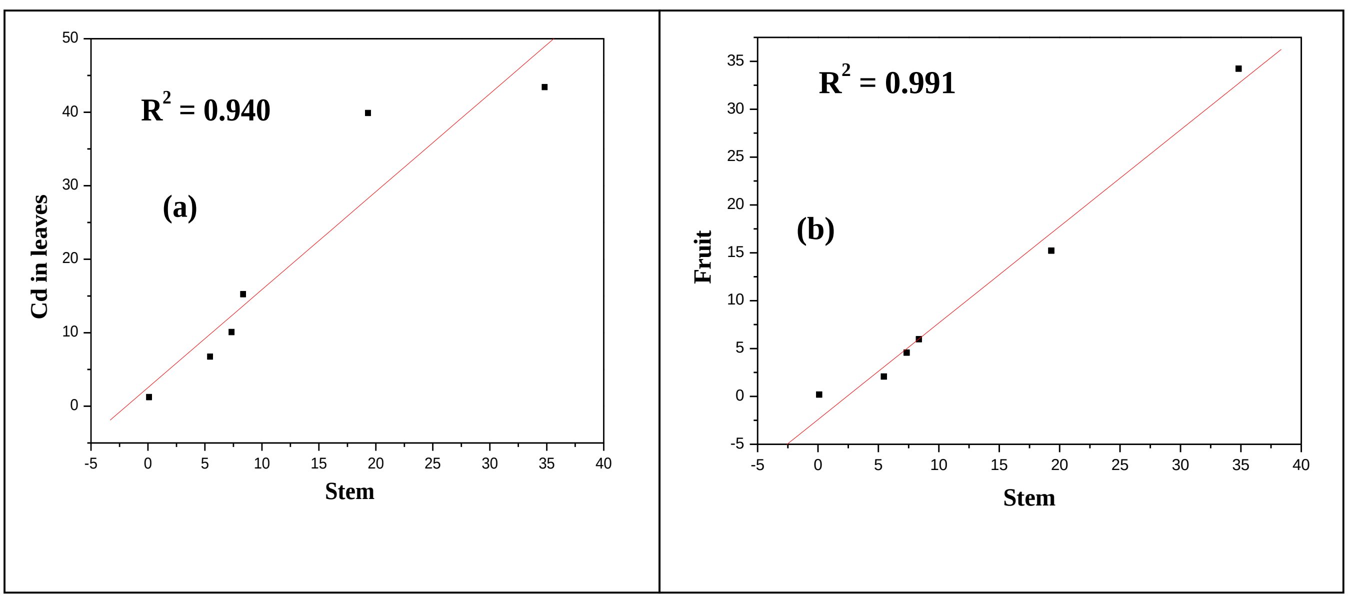
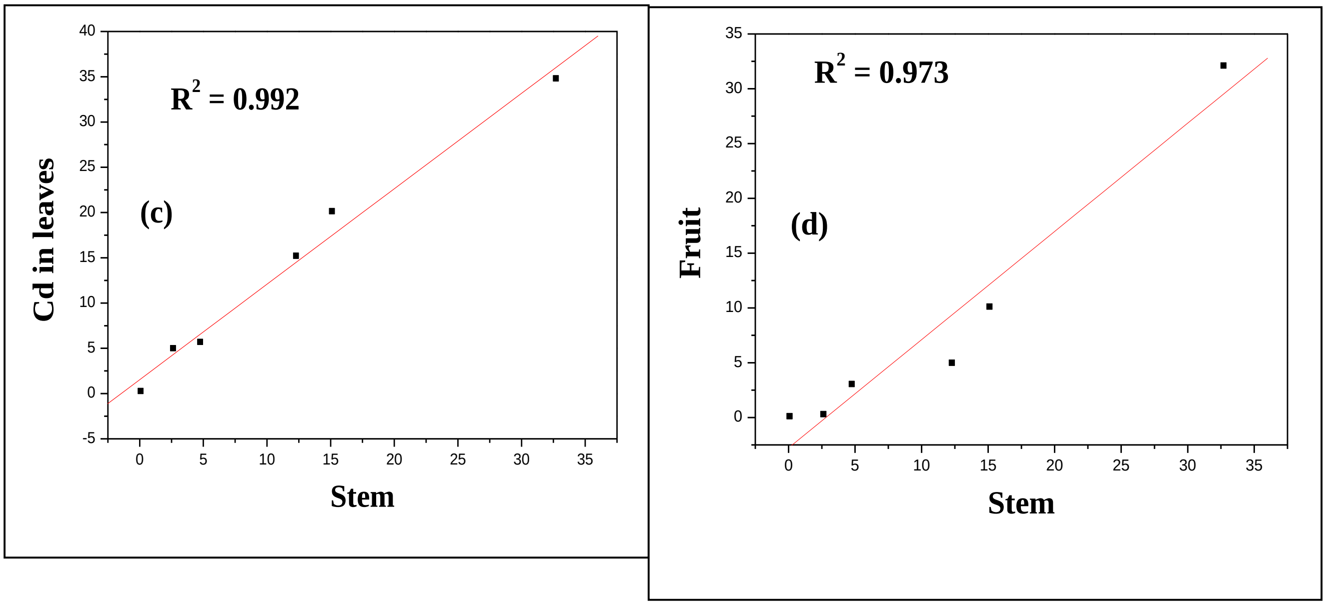


Figure 2: Cadmium distribution among organs of beans (mg / Kg)

Beans and sweet potatoes accumulated most of the cadmium in their leaves ((1.15; 6.64; 10; 15.15; 39.80 and 43.32 mgkg^{-1} for sweet potatoes) and (0.20; 4.93; 5.63; 15.15; 20.08 and 34.75 mg kg^{-1}for beans) from A6, A_5, A4, A_3, A_2 andA_1 respectively. The lowest amounts of this element were found in the fruit or edible roots of both plants and cadmium concentration declined in the order: leaves > stems > fruits (edible roots) in both plants. Although the underground edible roots (for sweet potatoes) belongs to the root structure and in contact with the soil directly, as compared to the non-edible root (for beans), they were differences in the absorption and accumulation capacities of Cd. From the above results, it was observed that sweet potatoes had the highest concentration in leaves, stems and fruits than beans. This is in agreement with the findings of Cheng & Huang (2007) [2] and Sêkara *et al*. (2005) [20] indicating that, plants of the Leguminosae family are characterized by low trace element absorption.

Significant coefficients of determination were found between the amount of cadmium in the stem and other organs of both plants: leaves (R^2=0.940), fruits (R^2 =0.991) for sweet potatoes and leaves (R^2=0.992), fruits (R^2 =0.973) for beans (Figures 3 and 4).





4. DISCUSSION

The allowable cadmium concentration in crops as stipulated by the various nations generally falls between 0.05 to 1.0 mg kg^{-1}. This result indicates that beans and sweet potatoes grown in contaminated soil as obtained in this study are not suitable for human consumption. It was observed that the control plants growing in the un-contaminated soil showed increasing cadmium accumulation in the edible roots / grains, stems and leaves as shown in Table 1 and Table 2 above. The results obtained in this research, indicated that the edible roots / grains of the two crops (sweet potatoes and beans) have somewhat high capacity of absorbing and accumulating cadmium. These quantities of cadmium in the edible root are very dangerous for human health since as the values exceed the allowable limit and may cause serious health damages on humans such as: the perturbation or the destruction of kidney filtration mechanisms in cells, Stomach pain and serious vomiting, bone fractures, reproduction failures and even probable infertility, Central Nervous System disorders [21]. Therefore, soils with slightly high cadmium contamination should not be used for growing sweet potatoes and beans and any other food crops.

5. CONCLUSION

This study was aimed at investigating the extent of absorption of Cd in soils by food crops and its distribution in various plant parts. The results of this study indicated that sweet potatoes and beans are able to absorb cadmium. Sweet potato was characterized by the highest absorption capacity as far as cadmium is concerned. The edible roots of sweet potato and beans are nutrient-storing organs. Thus, heavy metals such as cadmium may accumulate in the edible roots along with the stored nutrients. In this research, the cadmium concentration in the edible roots of all the two plants exceeded the allowable concentrations by most nations. The periodic monitoring of heavy metal concentrations in all the agricultural products is essential and highly recommended, to assess the temporal trends in human exposure to these metals. This is also necessary due to increasing uses of fertilizers, pesticides and veterinary chemicals in food production. Sweet potato and beans used in this research are not suitable for consumption. It is recommended that soils with slight cadmium contamination be classified as unsuitable for growing crops such as sweet potato and beans, especially sweet potato and any other food crops.

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