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EXPLORING THE IMPACT OF CITRIC ACID ON CADMIUM REMOVAL BY WATER LETTUCE (*Pistia stratiotes)* THROUGH RHIZOFILTRATION IN A HYDROPONIC SYSTEM

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ABSTRACT

Water lettuce (*Pistia stratiots*) was utilized for rhizofiltration of water containing 5 to 20 mg Cd L^{-1} in a water culture system with a 5-L pot capacity. The contact time for the treatments was one, two, and three weeks. The weight of plant growth was recorded for different Cd concentrations ranging from 0 to 20 mg Cd L^{-1} without citric acid (CA) addition, which resulted in the following values: 21.05, 14.38, 12.19, 10.29, and 7.41. Cd removal was observed for all Cd treatments without the use of CA. The average removal of Cd was recorded as 384.83, 485.01, 562.50, and 619.87 µg Cd pot^{-1} for treatments of 5, 10, 15, and 20 mg pot^{-1}, respectively. The corresponding removals via root uptake were 71.80, 92.14, 116.37, and 134.93 µg pot^{-1}, respectively. The Cd concentration in shoots varied from 25 to 80 µg Cd g^{-1}, while in roots, it ranged from 38 to 97 µg Cd g^{-1} dry matter. The addition of CA to water increased Cd removal due to its chelating effect, which made the metal more easily available. Untreated plants (without CA) showed low Cd levels, whereas CA-treated plants demonstrated the capability of extracting significant amounts of Cd. The chelating effect of CA on the metal increased its availability to water lettuce (*Pistia stratiots*).

Key Words: Rhizofiltration, Cadmium, Aquatic plants, Hydroponic systems, Citric acid, Water pollution, Environmental remediation

INTRODUCTION

The pollution of the River Nile in Egypt has contributed to the increase in cadmium levels in the environment **(Fawzy *et al.*, 2012). Sanita and Gabrielli (1999)** stated that cadmium is a harmful element that negatively affects on plant growth and development. It is released into the environment by various human activities such as power generation, metalworking, and urban traffic, and is commonly used in products like batteries and plastic stabilizers. Cadmium is highly toxic and soluble in water, making it a major contaminant **(Pinto *et al.*, 2004).** Different types of lettuce and plant species have varying levels of cadmium accumulation, as reported by **John and Laerhoven (1976)** .

The process of using living plants to cleanse soil and water is known as phytoremediation, as noted by several studies **(Sherameti and Varma 2015 ; Bonanno *et al.,* 2017 and Kumar *et al.,* 2017**. One specific phytoremediation process is rhizofiltration or phytofiltration, which involves using plants to remove metals from contaminated water, as discussed in studies by **Espinoza-Quinones *et al.,* (2008 & 2009) and Abdelsalam *et al.,* (2015).** This process can occur through adsorption or precipitation of elements onto plant roots or absorption followed by sequestration in roots, as seen with metals such as Pb, Cd, Cu, Fe, Ni, Mn, Zn, Cr, as well as radionuclides like 90 Sr, 137 Cs, 238 U, and 236 U **(Dushenkov *et al.,* 1995 and 1997a & b).** Aquatic plants, such as water lettuce (***Pistia stratiotes***), water hyacinth (***Eichhornia crassipes***), and duckweed (***Lemma gibba***), can also be used for phytoremediation to remove pollutants from polluted water, including heavy metals, as shown by **Odjegba and Fasidi (2004) ; Miretzky *et al.,* (2004 & 2006) and Olguin *et al.,* (2017).** These plants can also be effective in nutrient uptake from water bodies, making them useful in water quality assessment and treatment systems, as discussed by **Fawzy *et al.,* (2012) and Khankhane *et al.,* (2014).** Water lettuce, specifically, has been identified as a useful species for phytoremediation due to its extensive spreading roots and high capacity for taking up impurities, as noted by **Williams and Hecky (2005) ; El-Gendy *et al.,* (2005) and Gupta *et al.,* (2012).** It is also inexpensive for propagation and has been found to be effective in accumulating heavy metals from wastewater in Egypt, as reported by **Galal and Farahat (2015)** & **Galal *et al.,* (2018).** It can be found growing in slow-flowing canals in North Nile Delta, in Embaba near Cairo, and in stagnant waters around Fariskur in the North Delta and lake Mariut and lake Manzala, **(Tackholm, 1974 ; Boulos, 2005 ; Galal *et al.,* 2012 ; Galal and Farahat 2015).**

Phytoremediation involves using specific chemicals, either synthetic or organic to improve plant growth and increase metal uptake. This method, known as chemo-remediation, utilizes chelating chemicals such as citric acid (CA), diethylene-triamine-pentaacetic acid (DTPA), and ethylene-diamine-tetraacetic acid (EDTA), which help plants remove metals more effectively. Compared to synthetic chelating agents, CA has higher biodegradability and less leaching risks, making it a preferred choice. Additionally, CA has been found to enhance plant uptake of other nutrients and has proven effective in mobilization and phytoextraction of cadmium (Cd). Studies by **Turgut *et al.,* (2004) ; Evangelou *et al.,* (2007) ; Murakami *et al.,* (2007) ; Melo *et al.,* (2008) ; Sinhal *et al.,* (2010) ; Wuana *et al.,* (2010) ; Szczygłowska *et al.,* (2011) ; Bareen (2012) ; Yeh *et al.,* (2012) ; Anwer *et al.,* (2012) ; Chigbo and Batty (2013) ; Freitas *et al.,* (2013) and Abdelsalam *et al.,* (2015)** have all reported positive outcomes using chelating chemicals to aid in phytoremediation.

The objective of the current study was to assess the phyto-extraction effectiveness of water lettuce (***Pistia stratiots***) using citric acid.

MATERIALS AND METHODS

To assess the effectiveness of water lettuce (***pistia stratiotes***) in removing cadmium (Cd) from polluted water, pot trials were carried out. Two separate experiments were conducted, one without citric acid (CA) and another with citric acid (CA) ($C_6h_8O_7$), which has a relative molar mass of 192.12 g/mol^{-1}, at a rate of 5 mM pot^{-1} **(Hassan *et al.*, 2016).**

The experiment was designed as a randomized complete block, factorial with 3 replicates. There were two factors with 5 treatments for factor 1 (Cd content in water) ranging from 0 to 20mg Cd L^{-1}in the form of $CdCl_2$, and 3 treatments for factor 2 (time of exposure duration of roots into the water culture) ranging from one week to three weeks. The total number of treatments was 45, with 15 treatment combinations. Each pot (PVC) had a diameter of 20cm and a height of 40cm, filled with 5L of Hoagland nutrient solution, maintaining a pH between 7.1-7.4. The pH of the culture water was maintained between 6.0-6.5 using 0.1M HCl and 0.1M NaOH, as described by **Wahla and Kirkham (2008) and Rolli *et al.*, (2017).** The plants were collected from El-Serw village, south of Manzalah lake, northeastern Egypt, identified according to **Tackholm (1974),** and washed with distilled water before the experiments. Two fresh and healthy plants of the same size and weight were selected per pot, and the experiments were conducted during the summer of 2020 at the experimental farm of Kafr El-Hamam Agricultural Research Station in El Sharkia Governorate, Egypt. The plants were acclimatized in a Hoagland solution for 10 days before exposure to heavy metal contamination. $CdCl_2$ was used at concentrations of 0, 5, 10, 15, and 20 mgL^{-1} in the absence and presence of citric acid. The effects were assessed at one week, two weeks, and three weeks. The volume of the solution was kept constant by adding deionized water. Cd was determined after digestion with a perchloric, nitric, and sulphuric acid mixture, and both water and plant samples were analyzed for Cd. The removal efficiency was calculated using the equation described by **Ganjo and Kwhakaram (2010) & Kumar *et al.*, (2017):**

$$R(\%) = \frac{C_0 - C_t}{C_t}$$

Where R is the removal efficiency in per cent (%), while C_0 and C_t refer to the initial and residual (after t days) heavy metals concentrations in the aqueous solution (mg L^{-1}), respectively. A diagram of the experimental setup is shown in Fig. 1.

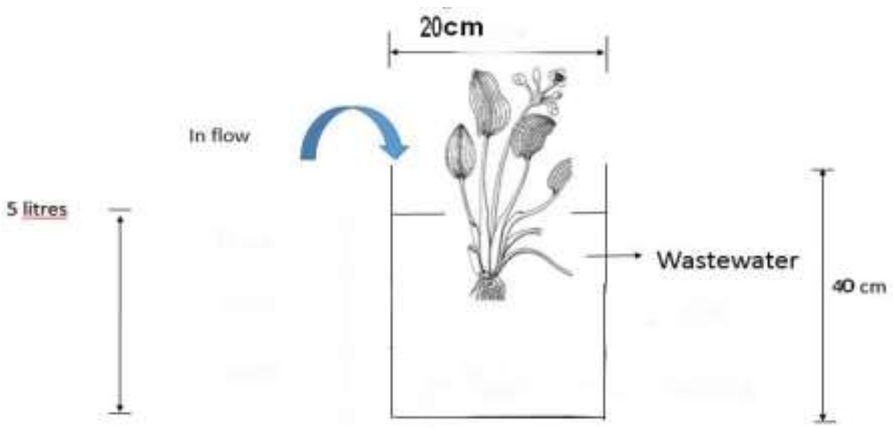

Fig 1: A scimatic drawing rhizo-filtration set up

Removal of cadmium from water was calculated as follows:

$R = (C_1) - (C_0)$

-where R =The removal of Cd from water culture

-,C_1= Final concentration of cadmium in plants after exposure and C_0=Concentration of copper in plants before exposure

RESULTS AND DISCUSSION

Plant growth:

Plant growth increased with time; the three weeks growth was 21.46% greater (on average) than the one week growth (Tables 1 to 4 and Fig 2 & 3). On the other hand the growth decreased with increased concentration of Cd in water exhibiting a retarding effect by Cd without citric acid. Weight of plant growth (roots + shoots) was 21.05,14.38,12.19, 10.29 and 7.41 for treatments of 0 , 5 , 10, 15 and 20 mg Cd L^{-1} respectively , exhibiting a progressive decrease with the increase in Cd in the culture water . However, cadmium with CA (citric acid) increasing were 21.05 , 16.10, 14.08, 12.27 and 9.33 respectively for the same abovementioned parameters with cadmium rates of 0 , 5 , 10, 15 and 20 mg CdL^{-1} . The biomass of plants was determined as dry weight. The weight decreased with the increase in the concentration of cadmium without CA .These results agree with the findings of **Sani-Ahmed *et al.*, (2015)**, who observed severe adverse effect of lettuce plants grown in nutrient solutions containing 3 to 12 mg Cd L^{-1}. Also, **Chiang *et al.*, (2006)** noted that biomass decrease in plants under presence of Cd. Indirect toxicity to plants could occur through occupation of Cd in place of useful plant nutrients **(Taiz *et al.*, 2009)**. Inhibition of translocation of plant nutrients and some organic acids can occur due to the existence of Cd in plant or in its root vicinity (**Jadia and Fulekar,**

2008). On the other hand, presence of citric acid had positive effect in increasing the yield of plants. Weight of plant growth (roots + shoots) was 21.05,16.10,14.08,12.27 and 9.33 for treatments 0 , 5 , 10, 15 and 20 mg Cd L^{-1} respectively compared with the absence of citric acid in culture solution .The alleviation effect of citric acid on the toxicity of cadmium to plant in harmony with those recorded. **(Haouari *et al.*, 2012)**, found that CA with Cd^{2+} addition significantly prevented praline accumulation, when compared with the Cd^{2+} treatment alone, suggesting a protective role of CA in preventing oxidative stress in Jute mallow. Cd^{2+} cannot directly produce ROS. **Chen *et al.*, (2003)** reported that when cadmium is applied with citric acid, a consequence of the decrease of the solution pH and consequent increase of mobility, leading to a sustainable increase of the Cd uptake in its less toxic forms. In addition **Ehsan *et al.*, (2014)** noted alleviating effect of citric acid to Rapeseed (*Brassica napus*), under Cd high contents in the root zone. High contents of Cd around plant roots causes disruption to plant chloroplasts, protein synthesis, and photosynthesis **(Vassilev *et al.*, 1995 and Ali *et al.*, 2013 a&b).** Disruption of chloroplasts was attributed to a rise in the activity of the chlorophyllase enzyme **(Hegedus *et al.*, 2001)**. The alleviating effect of citric acid may be due to increases in chlorophyll contents and gas exchange rate **(Wang *et al.*, 2004).**

Table 1: Using water lettuce (*Pistia stratiots*) to remove Cd from water culture: shoots & roots dry weight (g pot^{-1}) with exposure for one, two and three weeks without citric acid

Time duration of roots in culture solution (T)	Initial Cd content in water culture solution (mg L^{-1}) (C)					
	0	5	10	15	20	Mean
	Growth weight of whole plants (shoots+roots)					
One week	18.80	17.41	15.25	12.11	10.55	14.82
Two weeks	21.05	14.30	11.75	10.41	6.55	12.81
Three weeks	23.30	11.33	9.57	8.35	5.15	11.54
Mean	21.05	14.38	12.19	10.29	7.41	
LSD 0.05 :	C: 1.74	T: 2.85	CT: ns			
% decrease in weight of plants due to Cu presence in water						
One week	-	7.39	16.22	35.58	43.90	25.77
Two weeks	-	32.06	44.18	50.54	68.90	48.92
Three weeks	-	51.37	58.90	64.16	77.89	63.08
Mean	-	22.70	39.76	50.10	63.56	

Red= reduction %={(control weight – treatment weight)/control weight} x 100

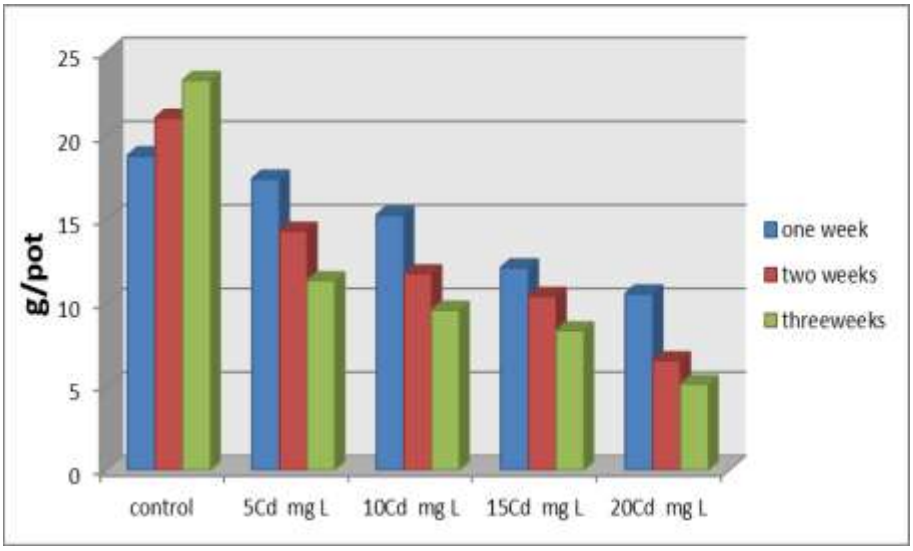

Fig 2: Using water lettuce (*Pistia stratiots*) to remove Cd from water culture: shoots & roots dry weight (g pot-1) with exposure for one, two and three weeks without citric acid.

Table 2: Using water lettuce *(Pistia stratiots)* to remove Cd from water culture: shoots & roots dry weight (g pot^{-1}) with exposure for one, two and three weeks with citric acid

.Time duration of roots in culture solution (T)	Initial Cd content in water culture solution (mg L^{-1}) (C)					
	0	5	10	15	20	Mean
	Growth weight of whole plants (shoots+roots)					
One week	18.80	18.50	16,90	14.36	11.75	16.06
Two weeks	21.05	16.00	13.65	12.05	8.95	14.34
Three weeks	23.30	13.80	11.70	10.40	7.78	13.30
Mean	21.05	16.10	14.08	12.27	9.33	
LSD 0.05 : C: 1.19 T: 2.36 CT: ns						
% decrease in weight of plants due to Cd presence in water						
One week	-	1.59	10.10	23.60	37.50	21.44
Two weeks	-	24.00	35.15	42.75	55.48	39.34
Three weeks	-	40.77	50.00	55.36	66.80	53.23
Mean	-	22.12	31.75	40.57	53.26	

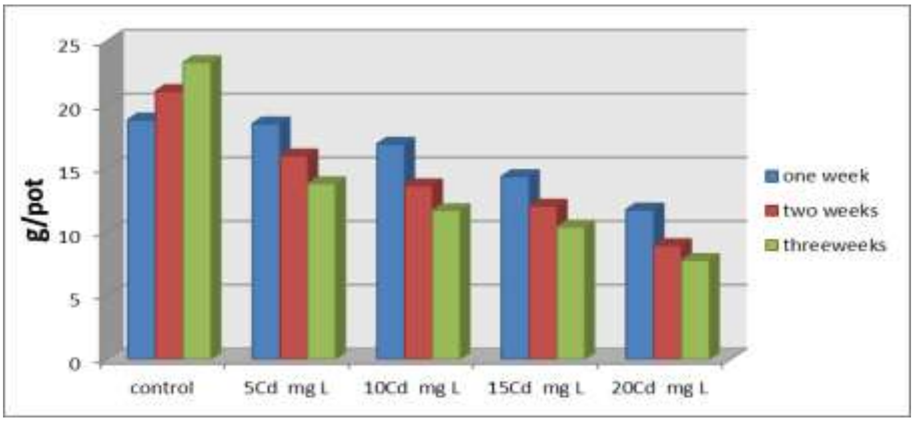

Fig 3: Using water lettuce (*Pistia stratiots*) to remove Cd from water culture: shoots & roots dry weight (g pot-1) with exposure for one, two and three weeks with citric acid.

Table 3: Using water lettuce *(Pistia stratiots)*) to remove Cd from water culture: Growth dry weight of shoots and roots as affected by water Cd without citric acid.

Time duration of roots in culture solution (T)	Initial Cd content in nutrient solution mg L^{-1} (C)					
	0	5	10	15	20	Mean
	Shoots dry weight ($gpot^{-1}$)					
One week	16.20	15.11	13.10	10.11	8.75	12.65
Two weeks	18.15	12.15	9.85	8.71	5.15	10.80
Three weeks	20.15	10.14	8.17	7.15	4.20	9.96
Mean	18.16	12.46	10.37	8.65	6.03	
LSD 0.05 : C:0.97 T: 1.98 CT: ns						
% decrease in shoot weight of due to Cd presence in water culture						
One week	-	6.72	19.13	37.59	45.98	27.35
Two weeks	-	33.05	45.73	52.01	71.62	50.60
Three weeks	-	49.67	59.45	64.51	79.15	63.19
Mean	-	29.81	41.43	51.37	65.58	
Roots weight $gpot^{-1}$						
One week	2.60	2.30	2.15	2.00	1.80	2.17
Two weeks	2.90	2.15	1.90	1.70	1.40	2.01
Three weeks	3.15	1.40	1.20	1.18	0.95	1.57
Mean	2.88	1.87	1.80	1.63	1.38	
	LSD 0.05 : C:0.15 T: 0.46 CT: ns					
% decrease in root weight due to Cd presence in water						
One week	-	11.53	17.30	23.07	30.76	20.66
Two weeks	-	25.86	34.48	41.37	51.72	38.35
Three weeks	-	55.50	61.90	62.53	69.84	62.36
Mean	-	30.96	37.89	42.32	50.77	

Table 4: Using water lettuce *(Pistia stratiots))* to remove Cd from water culture: Growth dry weight of shoots and roots as affected by water Cd with citric acid

Time duration of roots in culture solution (T)	Initial Cd content in nutrient solution mg L^{-1} (C)					
	0	5	10	15	20	Mean
	Shoots dry weight (gpot^{-1})					
One week	17.40	16.00	14.50	12.11	9.80	17.45
Two weeks	19.25	13.50	11.60	10.15	7.15	15.41
Three weeks	21.35	11.73	9.80	8.90	6.50	14.57
Mean	19.33	13.74	11.96	10.38	7.81	
LSD 0.05 : C:0.97 T: 1.98 CT: ns						
% decrease in shoot weight of due to Cd presence in water culture						
One week	-	8.04	16.66	30.40	43.67	24.69
Two weeks	-	29.87	39.74	47.27	62.85	44.93
Three weeks	-	45.05	54.09	58.31	69.55	56.75
Mean	-	27.65	36.83	45.32	58.69	
Roots weight gpot^{-1}						
One week	3.00	2.60	2.45	2.10	1.95	2.42
Two weeks	3.32	2.30	2.10	1.95	1.78	2.29
Three weeks	3.70	2.10	1.90	1.56	1.24	2.10
Mean	3.34	2.33	2.15	1.87	1.65	
	LSD 0.05 : C:0.15 T: 0.46 CT: ns					
% decrease in root weight due to Cd presence in water						
One week	-	13.33	18.33	30.00	35.00	24.16
Two weeks	-	30.72	36.74	41.26	46.36	38.77
Three weeks	-	43.24	48.46	57.83	66.48	54.00
Mean	-	29.09	34.51	45.94	49.28	

Removal of Cd from the water culture:

Plants removed Cd without and with citric acid from the water culture (Tables 5 and 6). Plants grown in the no-Cd showed no detectable Cd. The average removal of Cd through uptake over the 5 Cd treatments by plant (shoots + roots) were 58.68,384.83, 485.01, 562.50 and 619.87 ug Cd pot^{-1} for 5Cd treatments (average of the three immersion times) . Comparable uptakes by roots were 8.16, 71.80, 92.14, 116.37 and 134.93 ug pot^{-1} respectively. The progressive decrease is in line with the increase in Cd in growth media the decreased plant growth associated with the increased Cd in the water culture. Contents of Cd in root were generally greater than in shoots. Contents in roots averaged 38, 51, 71 and 97 µg g-^{1} (an average of 64.25 µg g^{-1}). Comparable contents in shoots were 25, 37, 51 and 80 µg g^{-1} (average of 48 µg g^{-1}) without citric acid addition.

As for the effect of cadmium with citric acid application the obtained data clearly indicate that the average removal of Cd through uptake amounts by plant (shoots+roots) were 58.68,472.89,567.38,681.24 and 749.07 µg Cd pot^{-1} for 5 treatments respectively while uptakes by roots were 8.16, 89.61, 126.39, 148.70 and 175.19 µg pot^{-1} for the 5 Cd treatments respectively.

Table 5: Using water lettuce (*Pistia stratiots*) to remove Cd from water culture: Cd removal by plants (µg pot^{-1}) with exposure for one, two and three weeks without citric acid

Time duration of roots in culture solution (T)	Initial Cu content in water culture solution (mg L^{-1}) (C)					
	0	5	10	15	20	Mean
	Cd removed from culture solution by 'shoots+roots'					
One week	56.54	296.34	387.56	465.81	510.23	458.47
Two weeks	59.37	368.92	489.34	577.34	627.12	584.81
Three weeks	60.13	489.23	578.15	644.37	722.26	646.86
Mean	58.68	384.83	485.01	562.50	619.87	
LSD 0.05	C: 7.4	T: 31.1	CT: 35.9			
Cd removed from solution culture by shoots						
One week	49.32	243.17	324.70	377.64	407.23	280.41
Two weeks	51.65	302.94	398.22	469.78	501.45	344.80
Three weeks	50.57	392.96	455.70	491.08	546.12	387.28
Mean	50.51	313.03	392.87	446.16	484.93	
LSD 0.05 :	C: 8.3	T: 29.7	CT: 34.4			
Cd removed from culture solution by roots						
One week	7.22	53.17	62.86	88.17	103.00	62.88
Two weeks	7.72	65.98	91.12	107.65	125.67	79.62
Three weeks	9.56	96.27	122.45	153.29	176.14	111.54
Mean	8.16	71.80	92.14	116.37	134.93	
LSD 0.05 :	C:1.5	T: 6.3	CT: 8.3			

Table 6: Using water lettuce (*Pistia stratiots*) to remove Cd from water culture: Cd removal by plants (µg pot-1) with exposure for one, two and three weeks with citric acid

Time duration of roots in culture solution (T)	Initial Cu content in water culture solution (mg L^{-1}) (C)					
	0	5	10	15	20	Mean
	Cd removed from culture solution by 'shoots+roots'					
One week	56.54	352.17	447.65	560.13	630.67	409.43
Two weeks	59.37	489.24	572.32	695.15	764.56	516.12
Three weeks	60.13	577.27	682.17	788.45	852.00	592.20
Mean	58.68	472.89	567.38	681.24	749.07	
LSD 0.05	C: 9.4	T: 33.1	CT: 35.9			
Cd removed from solution culture by shoots						
One week	49.32	286.94	370.31	465.92	505.78	335.65
Two weeks	50.57	401.08	446.13	553.59	598.04	410.09
Three weeks	51.65	461.81	506.34	578.11	617.82	442.93
Mean	50.51	383.27	440.92	532.54	573.88	
LSD 0.05	C: 10.3	T: 28.9	CT: 30.7			
Cd removed from culture solution by roots						
One week	7.22	65.23	77.34	94.21	124.89	74.77
Two weeks	7.72	88.16	126.19	141.56	166.52	106.03
Three weeks	9.56	115.46	175.66	210.34	234.18	149.04
Mean	8.16	89.61	126.39	148.70	175.19	
LSD 0.05 :	C: 2.2	T: 7.3	CT: 9.4			

According to **Lambers *et al.*, (2006),** the use of citric acid and other low molecular organic acids leads to an increase in the uptake of cadmium. This is because they release protons and electrons that eliminate metals in the rhizosphere, as indicated by **Jones and Brassington (1998). Williams *et al.*, (2006)** observed a similar phenomenon in Indian mustard plants, concluding that citric acid was responsible for the increased uptake of Cd. The accumulation of metals in plants can occur through various processes, such as mobilization and uptake compartmentalization, sequestration within plant roots, an increase in the efficiency of xylem loading, and storage in leaf cells, as supported by **Kabata-Pendias and Pendias (1989) ; Marschner (1995), Williams (2000) and Clemens (2001).**

CONCLUSION

From the current findings, it can be inferred that rhizofiltration may be a cost-effective and suitable solution. The critical factor for success is selecting the right plant species. According to the study results, ***Pistia stratoites*** can be utilized along with citric acid to eliminate Cd from polluted water. Therefore, implementing phytoremediation via rhizofiltration with *Pistia stratoites* seems to be a practical proposition that can be done at a low cost.

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استكشاف تأثير حامض الستريك على إزالة الكادميوم بواسطة نبات خس الماء من خلال الفلترة الجذرية في نظام الزراعة المائية

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العناصر الثقيلة من الملوثات التي يصعب ازالتها من البيئه حيث لاتخضع للتكسير الكيميائى أو البيولوجى توجد عدة طرق لازالة العناصر الثقيله من مياة الصرف الصناعى او الزراعى الملوثه ولكنها ذات تكلفه مرتفعه لكن يمكن ازالة التلوث باستخدام النباتات المائية الطافية مثل خس الماء.

تم اجراء تجربة استخدم فيها النبات الطافى خس الماء عن طريق نموالجذور في اصص تملأ محاليل مغذية بها تركيزات متزايدة من الكادميوم هي 0 و 5 و 10 و 15 و 20 مليجرام \ لتر فى المحلول المغذى (حجم 5 لتر)وقد اضيف الكادميوم في صورة كلوريد كادميوم; ($CdCl_2$) وذلك لمدة اسبوع و 2 و 3 اسابيع.

كان نمو النبات 21.05 ، 14.38 ، 12.19 ، 10.29 ، و 7.41جرام لكل اصيص لعلاج 0 ، 5 ، 10 ، 15 و 20 ملغ من CdL^{-1} في غياب حمض الستريك (CA) على التوالي ، وعلى الجانب الآخر من اضافة حمض الستريك ظهر تأثير ايجابى على إنتاج الكتلة الحيوية.

حدثت إزالة الكادميوم من المياه الملوثة مع كل المعاملات بالكادميوم بدون CA. وكانت المتوسطات 384.83 ، 485.01 ، 562.50 و 619.87 ميكروغرام من الكادميوم لكل اصيص عند معاملات 5،10،15 و 20 ملجرام كادميوم لكل لتر على التوالي. كانت عمليات الإزالة الناتجة عن امتصاص الجذر 71.80 و 92.14 و 116.37 و 134.93 ميكرو جرام لكل اصيص على التوالي. تراوح تركيز الكادميوم في المجموع الخضرى من 25 إلى 80 ميكروجرام كادميوم لكل جرام مادة جافة ، بينما تراوح في الجذور من 38 إلى 97 ميكروغرام كادميوم لكل جرام مادة جافة.

أدت إضافة CA في المياه الملوثة إلى زيادة إزالة الكادميوم حيث ان تأثير المخلبى لمادة CA ادى الى ان الكادميوم اقابل للذوبان ومتاح بسهولة أكبر. وبالتالي ، كانت تركيزات الكادميوم في الاصص المحتوية على نبات خس الماءغير المعالجة (بدون CA) منخفضة ، في حين أن النباتات المعالجة CA كانت قادرة على استخراج كميات كبيرة من الكادميوم. توصى الدراسة باستخدام مخلب CA لازالة الكادميوم مع نبات خس الماء لانه يجعل الكادميوم متاحًا بسهولة لخس الماء (*Pistia stratiots*).