Application Of *Coriandrum Sativum* Biomass In The Removal Of Chromium (VI) From Polluted Waters

Ana Sofia Reyes Barbosa
Facultad de Ciencias Químicas
Universidad Autónoma de San Luis Potosí
San Luis Potosí, México
Anasofiareyes436@hotmail.com

Martha E. Purata Díaz
Facultad de Ciencias Químicas
Universidad Autónoma de San Luis Potosí
San Luis Potosí, México
Martha_eugenia96@hotmail.com

Paulina Olivo Fat
Facultad de Ciencias Químicas
Universidad Autónoma de San Luis Potosí
San Luis Potosí, México
Pau.olivo.f@outlook.com

Juan F. Cárdenas González
Unidad Académica Multidisciplinaria Zona Media
Universidad Autónoma de San Luis Potosí. Río Verde, San Luis Potosí, México
jfkardenas_08@hotmail.com

Erika Enríquez Domíngez
Facultad de Ciencias Químicas
Universidad Autonóma de San Luís Potosí
San Luís Potosí, S.L.P. México
erika.dominguez@uaslp.mx

Adriana S. Rodríguez Pérez
Unidad Académica Multidisciplinaria Zona Media
Universidad Autónoma de San Luis Potosí. Río Verde, San Luis Potosí, México
asarai28@hotmail.com

Víctor M. Martínez Juárez
Área Académica de Medicina Veterinaria y Zootecnia
Universidad Autónoma del Estado de Hidalgo
Hidalgo, México
victormj@uaeh.edu.mx

Juana Tovar Oviedo
Facultad de Ciencias Químicas
Universidad Autónoma de San Luis Potosí
San Luis Potosí, México
jtoviedo@uaslp.mx

Ismael Acosta Rodríguez
Facultad de Ciencias Químicas
Universidad Autónoma de San Luis Potosí
San Luis Potosí, México
iacosta@uaslp.mx

***Abstract*—Coriander is a leaf vegetable, which belongs to the family of the *Chenopodiaceae*. It is an herbaceous plant with long and succulent petioles, large and erect leaves, that are used for human consumption due to its culinary uses and nutritional content. Its production is exposed to contaminating factors such as toxic metals from irrigation water, so it can accumulate them, and when ingested by humans, they can be poisoned with these heavy metals, and this accumulation characteristic can be used to try to eliminate these contaminates from soil contaminated with them. So, the objective of this work was analyzing the Cr (VI) removal capacity in aqueous solution by the *Coriandrum sativum* biomass, by the colorimetric method of Diphenylcarbazide, to evaluate the metal concentration. Biosorption at different pH was evaluated for 240 minutes. We too studied the effect of temperature in the range of 28 to 60°C, the removal at different initial concentrations of Cr (VI) and of biomass, and in contaminated niches. Therefore, the highest biosorption of the metal (100 mg/L) occurs within 180 minutes, at pH of 1.0, 1.0 g of natural biomass, and 28°C. According to temperature, the highest removal was observed at 60°C, in 12 minutes, when the metal is completely adsorbed. It was observed that higher concentration of the metal, the removal is less, and if the biomass concentration increases, this does not affect the removal of the metal in solution. Besides its removal efficiently the metal *in situ* (100% in soil and water contaminated, after 24 and 32 hours of incubation), with 5 g of biomass and 28°C; so, it can be used to eliminate it from industrial wastewater.**

Keywords—Chromium (VI), Removal, Chard Biomass, Detoxification

I. INTRODUCTION

Coriander is an aromatic herb with annual growth used regularly in the gastronomy of all the world. Its scientific name is *Coriandrum sativum* and it belongs to the apiaceae family. Can reach 40-60 cm in height and has a straight and round stem with deep green leaves in the shape of fan, round fruits, white flowers and brown or greyish roots. Other names used to refer to her, they are coriander, Chinese or Japanese parsley [1]. Its origin is uncertain, although different theories place it on the shores of the eastern

Mediterranean Sea, North Africa, and the Middle East, where it could find the temperate climate necessary to grow wild. It is known that its cultivation has been carried out for more than 5000 years and its use has been traced in ancient Egypt, from where it jumped to Ancient Greece (where it was eaten and used to create oils and perfumes) and the Roman Empire [2]. Despite what it may seem, it would be the Europeans who would introduce the plant to the American continent. Today its use is very common both in Mediterranean cuisine and in other oriental or South American cuisines. In Europe, perhaps Spain has been one of the last countries conquered by its flavor due to the presence of parsley, leaving the Canary Islands out, where it is an intrinsic part of its gastronomy. Central European countries use it profusely. Within Asian cuisines it is key to Thai or Indian cuisine and is also used in Chinese or Vietnamese cuisine. In South America there are many countries that use it in hundreds of recipes and elaborations: Mexico, Peru, Colombia, Venezuela, and Chile. It's that is very widespread also in Caribbean cuisine [2]. Everything is used from the plant, although the most common is to find the dried seeds or grind them to obtain a key powder in the elaboration of other products, or the fresh leaves, which are used both whole and chopped in all kinds of dishes as a dressing or garnish. In any case, the root, flowers, or seeds or fruits without drying are also used [3].

In addition to its enormous culinary possibilities, there is a certain consensus regarding the properties and health benefits of coriander consumption and even the essential oils that can be obtained from it. Its chemical analysis shows that it is composed of few calories, is practically free of fat and cholesterol, contains significant amounts of potassium and sodium, carbohydrates, and proteins. The fresh leaves are rich in vitamin C, while the dried and the seeds are rich in vitamin K. It also has vitamin A, B1, B2, iron, calcium, phosphorus, fiber, magnesium, and beta-carotene [4]. Coriander is a food capable of facilitate digestive processes and to alleviate episodes of constipation, gas, and colic. It is a good appetite stimulator and provides an expectorant sensation of freshness. In fact, the leaves are usually chewed as a remedy against halitosis. It also has diuretic effects that will help us reduce cholesterol and expel harmful substances from the body, in this aspect its chelating action is beneficial to eliminate heavy metals in the blood [1, 3, and 5]. It is also a powerful anti-inflammatory, analgesic and antiseptic, which is why it has been used regularly in medicine since its appearance, for example to treat diseases such as arthritis or to treat skin wounds. Its fungicidal, germicidal, and antispasmodic capacities have always been highly valued. It also has antioxidant and toning properties, in the production of phytopharmaceuticals, and the treatment of obesity [1, 6, 7, 8, and 9].

On the other hand, the great industrial growth has produced a progressive increase in wastewater discharges from the same and, therefore, a deterioration in water quality. Pollutants pose a danger to both human and environmental health. Some pollutants are of organic origin, such as hydrocarbons and pesticides, and inorganic, such as heavy metals, which play a fundamental role due to their importance and potential danger [10]. Some metals that are of great toxicological and exotoxicological importance are: mercury, chromium, lead, cadmium, nickel and zinc, which, once released into the environment, accumulate and concentrate in the soil and sediments, where they can remain for hundreds of years. affecting ecosystems. Therefore, it is more feasible to control the problem from the source and source of emission before they reach the environment [10]. In Mexico, agribusiness is one of the most important activities due to its growth in recent years, and it is the one that generates the most by-products that are not used [11], among which are: coffee bagasse, agave, maguey , sugar cane, straws from different crops, organic residues of fruits and vegetables [12]. In this regard, the use of different plant products with the ability to accumulate and/or bioadsorb heavy metals has been reported, which include *C. sativum* [13], and some reports are: its roots absorb high concentrations of Mn, Fe, Cu, and Zn from the soil [14], the decrease in cadmium levels present in wastewater [15], the adsorption of Cu (II) from aqueous solution by coriander seeds [16], the detoxification of heavy metals by medicinal herbs [17], the adsorption of Pb(II), Cu(II) and Zn(II) ions from aqueous solution of coriander seed powder [18], and the biosorption of pollutants in aqueous effluents [19]. Thus, there is a need to develop or find innovative low-cost adsorbents with an affinity towards metal ions for the removal of different heavy metals from aqueous solution, which leads to high adsorption capacity [10]. The objective of this study was to analyze in vitro biosorption of Cr (VI) by *C. sativum* biomass.

II. EXPERIMENTAL

A. Biosorbent used

The *C. sativum* biomass was obtained from the fruits harvested and offered in the marketplace Republic, between the months of March to May in 2019, of the capital city of San Luis Potosí, S.L.P. México. To obtain the biomass, the plant was washed with EDTA 10% (p/v) for 24 hours, and after with trideionized water during 3 days at constant stirring, with water changes every 12 hours. Subsequently, it was boiling 1 hour to removal traces of the color and dust and were dry at 80°C for 24 hours in an oven, ground in blender and stored in amber vials until use.

B. Biosorption studies and determination of hexavalent chromium.

For these studies, was used 1 g of dried biomass mixed with 100 mL of trideionized water containing 100 mg/L of the metal, in an Erlenmeyer flask at the desired temperature and pH. The flasks were agitated on a shaking bath Yamato BT-25 model. Samples of 5 mL were taken at different times, and centrifuged at 3000 rpm for 5 min. The supernatant liquid was separated and analyzed for chromium ions. Hexavalent chromium was quantifying by a Spectrophotometric method with Diphenylcarbazide [20, 21]. The information shown in the results section are the mean from three experiments carried out by triplicate.

III. RESULTS AND DISCUSSION

A. Effect of incubation time and pH

The optimum time and pH for Cr (VI) removal by *C. Sativum* biomass was 180 minutes and pH 1.0, at constant values of biosorbent dosage (1 g/100 mL), with an initial metal concentration of 100 mg/L, and a temperature of 28°C (Figure 1). It was used a pH meter Corning Pinnacle 530 model and we use nitric acid 1 M to maintain the pH, and these results are very similar to what was reported with chard in the same conditions [22], 270 minutes by the *Persea americana* biomass [23], an optimum time of 8 h for the removal of Cr(VI) by porous carbon derived from corn straw, 150 and 180 minutes for Cr (VI) removal using oleaster (*Elaeagnus*) seed and cherry (*Prunus avium*) stone biochar [24], and 120 minutes, with 150 mg/L of the same metal and 2.5 g/L of natural biomass with *Macadamia* nutshell powder oxidized by hydrogen peroxide solutions [25]. Changes in the cell permeability of unknown origin, could partly explain the differences founded in the incubation time, providing greater or lesser exposure of the functional groups of the cell wall of the biomass analyzed [10]. Adsorption efficiency of Cr (VI) was observe a maximum at pH 1.0 and 180 minutes with the biomass analyzed. The results showed with respect to the increase in pH resulted in decrease in the removal of the metal. It was reported an optimum pH 1.0 for chard [22], and *P. americana* biomass [23], for the removal of the same metal, pH of 1.5, for the Cr (VI) removal using oleaster (*Elaeagnus*) seed and cherry (*P. avium*) stone biochar [24], and a pH of 1-3, for the removal of the same metal by porous carbon derived from corn straw [26], Although other authors report an optimum pH 2.0 for epicarpio of *Vitis vinifera* L. [27], a pH of 3.0 by hydrothermal carbon-sphere-Fe_3O_4 [28], pH of 2.0 by modified Russian knapweed flower powder [29]. This was due to the dominant species (CrO_4^{2-} and $Cr_2O_7^{2-}$) of Cr ions in solution, which were expected to interact more strongly with the ligands carrying positive charges [30].

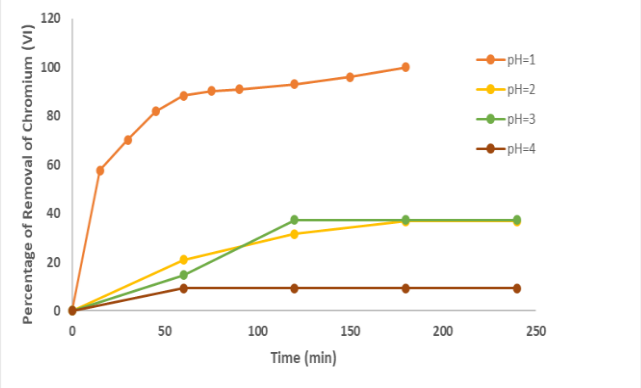

Figure 1. Effect of incubation time and pH on Chromium (VI) removal by *C. sativum* biomass. 100 mg/L Cr (VI), 100 rpm, 28°C. 1.0 g of biomass.

B. Effect of the temperature

On the other hand, temperature was found to be a critical parameter in the bioadsorption of metal (Figure 2). To maintain constant the temperature in all experiments, we use a shaking bath Yamato BT-25 model. The total removal was observed at 10 and 180 minutes of incubation, for 60°C and 28°C, respectively. These results are coincident for the biomasses of chard [22] and *P. americana* [23], by a reusable chitosan-modified multi-walled carbon nanotube composite [31], by dried twigs of *Melaleuca diosmifolia* [32], for the removal of Cr (VI). The increase in temperature increases the rate of removal of Cr (VI) and decrease the contact time required for complete removal of the metal, to increase the redox reaction rate [33].

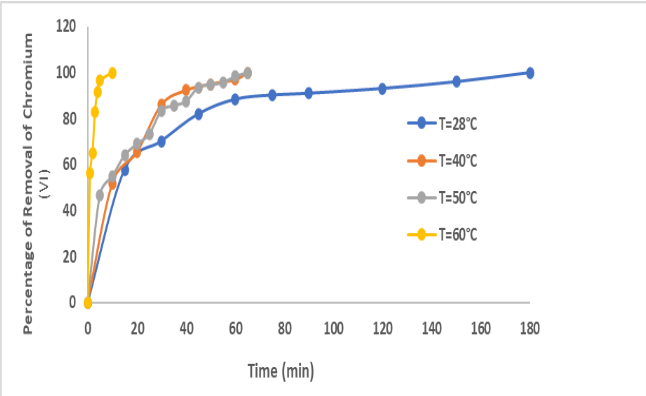

Figure 2. Effect of the temperature on Chromium (VI) removal by *C. sativum* biomass. 100 mg/L Cr (VI), pH 1.0, 100 rpm. 1.0 g of biomass.

C. Effect of initial metal concentration

We observe that the removal of metal was 100% at 4 and 24 hours, at 28°C, for 200 and 1000 mg/L, respectively (Figure 3). In addition, we observe the development of a blue-green and white precipitate, which changes more rapidly at higher temperatures (date not shown), and we determined this precipitate how Cr (III) [21]. The results are coincident for the removal of Cr (VI) by *B. vulgaris*, Var. Cycla [22], *P. americana,* [23], and *Cucumis sativus* biomasses [34], but are different for the chromium removal using *Platanus hispánica* aquenium, in it was found that the increase in the initial concentration led to an increase in the removal of the contaminant [35]. The increase in initial concentration of Cr (VI), results in the increased uptake capacity and decreased in the percentage of removal of the metal. This was due to the increase in the number of ions competing for the available functional groups on the surface of biomass [30, 33].

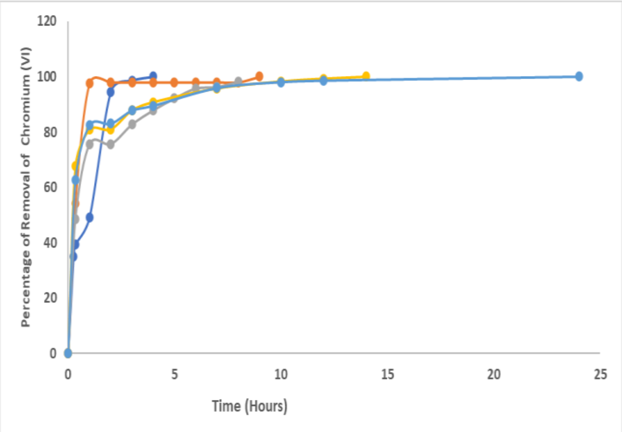

Figure 3. Effect of initial metal concentration on Cr (VI) removal by *C. sativum* biomass. pH 1.0, 100 rpm, 28°C. 200 mg/L, 400 mg/L, 600 mg/L, 800 mg/L, 1000 mg/L.

D. Effect of biosorbent dose

The influence of biomass concentration on the removal capacity of Cr (VI) is depict in Figure 4. If we increase the amount of biomass, the removal of the metal in solution decreased slightly, well the removal obtained was observed between 100%-80%, with 1-5 g of natural biomass, although it has been reported what with more biosorption sites of the same, because the amount of added biosorbent determines the number of binding sites available for metal biosorption [36]. These results are coincident for the removal of Cr (VI) by *B. vulgaris*, Var. Cycla [22] and *Cucumis sativus* biomasses [34]. Too, was reported a efficient removal of the metal if the biomass concentration was increased for oleaster (*Elaeagnus*) seed and cherry (*P. avium*) stone biochar [24], and using modified Russian knapweed flower powder to initial concentrations of Cr (VI) of 2, 10 and 15 mg/L with pH 2.0 [29].

Removal of Cr (VI) in industrial wastes with B. vulgaris biomass.

We adapted a water-phase bioremediation assay to explore possible usefulness of this biomass for eliminating Cr (VI) from industrial wastes. The biomass (5 g), was incubate with 10 g of non-sterilized contaminated earth with 100 mg/g, and wastewater containing 100 mg/L of Cr (VI) (adjusted), suspended in trideionized water to a final volume of 100 mL. It was observing that in 24 and 32 hours of incubation, the Cr (VI) concentration of earth and water samples decrease fully in both samples (Figure 5), and the decrease level occurred without change significant in total chromium content during the experiments (date not shown). In the experiment carried out without biomass, the Cr (VI) concentration of the earth samples decreased by about of 18% (date not shown); this might be caused by indigenous microflora and (or) reducing components present in the soil [22, 23, and 35]. These results coincide with the literature reports for other natural biomass, such as *B. vulgaris*, Var. Cycla [22], *P. americana,* [23], and *Cucumis sativus* [34], for a wastewater sample with Cr (III) (4 mg/L), Zn (II) (1 mg/L), Fe (II) (6 mg/L), Ni (II) (2 mg/L), and Cu (II) (31 mg/L) by *Macadamia* nutshell powder oxidized by hydrogen peroxide solutions [25], for seeds of *Moringa oleifera* with 1 g of biomass and concentrations of 10 to 150 ppm of Cu (II), Ni (II), and Cr (VI), with percentages of removal between 37-53%, 39-76%, and 11-33%, respectively [37], and for the Cr VI) biosorption, in aqueous solutions and in effluents industrial tannery, using biosorbent of eucalyptus tree waste leaves (*Globulus labill*), activated in acidic medium [38],

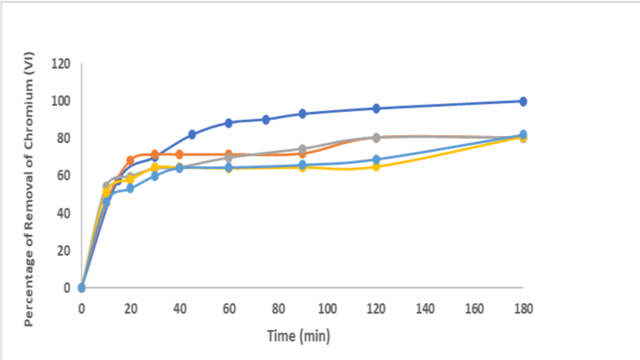

Figure 4. Effect of biomass concentration of *C. sativum* biomass, on the removal of 100 mg/L Cr (VI), 28°C, pH 1.0, 100 rpm.

1 g, 2 g, 3 g, 4 g.

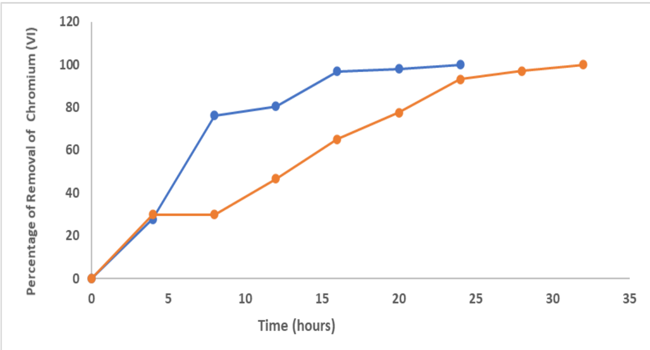

Figure 5. Removal of Cr (VI) in industrial wastes incubated with 5 g of *C. sativum* biomass. 28°C, 100 rpm, 10 g of contaminated earth with 100 mg/g and 100 mL of contaminated water with 100 mg/L. contaminated water, (100 mg Cr (VI)/L (adjusted).

Earth, Water

E. Conclusions

The biomass analyzed, showed complete capacity of biosorption of 100 mg/L of Cr (VI) in solution at different time of incubation, at 28°C, 100 rpm with 1 g of natural biomass, besides this removal the metal *in situ* (24 and 32 hours of incubation, with 5 g of biomass), in earth and water contaminated, respectively. These results suggest their potential applicability for the remediation of this metal from polluted soils in the fields.

F. References

[1] A.M. Ceballosa and G.I. Giraldo. "El cilantro (*Coriandrum sativum* L.) como fuente potencial de antioxidantes naturales". Vector 6. pp. 85-93. 2011.

[2] I. Rojas Puebla. "Calidad microbiológica en tres hortalizas producidas en el estado de México". UAEM. Programa de Maestría y Doctorado en Ciencias Agropecuarias y Recursos Naturales. Tesis Maestría. El Cerrillo Piedras Blancas, Toluca, México. 2017.

[3] F. Darughe, M. Barzegar, and M.A. Sahari. "Antioxidant and antifungal activity of Coriander *(Coriandrum sativum L.)* essential oil in cake". Int. Food Res. J. Vol. 19, No. 3 pp. 1253-1260. 2012.

[4] N. Rodríguez, X. Tovar, S, Sánchez y J, Noguez. "Efecto del agua residual y la lombricomposta sobre las características fisicoquímicas del suelo y desarrollo del cilantro (*Coriandrum sativum*)". Rev. Cien. Nat. y Agropec. Vol. 2, No. 3 pp. 458-467. 2015.

[5] M. Marín-Mendoza, M.A. Mariezcurrena-Berasain, E. Morales-Almaráz, A. Sánchez-Escalante, J.C. Vázquez-Chagoyan. "El extracto de cilantro (*Coriandrum sativum*) y su efecto antioxidante. Rev. Elec. Nueva Época Vet. Vol. 9, No. 1 pp. 67-83. 2018.

[6] A.F. Begnami, M.C.T. Duarte, V. Furletti, and V.L.G. Rehder. "Antimicrobial potential of *Coriandrum sativum* L. against different *Candida* species *in vitro*". Food Chemistry. Vol. 118 pp. 74–77. 2010.

[7] A. Khani and T. Rahdari. "Chemical Composition and Insecticidal Activity of Essential Oil from *Coriandrum sativum* Seeds against *Tribolium confusum* and *Callosobruchus maculatus*". ISRN Pharmaceutics. Vol. 2012, Article ID 263517, 5 pages.

[8] D.C. Cuenca Encarnación. "Producción de culantro (*Coriandrum sativum* L.) en suelos pesados en la granja experimental Santa Inés, como materia prima para la elaboración de fitofármacos". UT Mach. Unidad Académica de Ciencias Agropecuarias. Escuela de Ingeniería Agronómica. Tesis Licenciatura. Ingeniero Agrónomo. Machala, Ecuador. 2015.

[9] Z. Y. Arellano Vega, E. García Chávez, G. Alonso Soto Peña y M.L. Torres Rodríguez. "Evaluación del extracto acuoso de cilantro (*Coriandrum sativum* L.) sobre el metabolismo de glucosa y lípidos de ratas tratadas con dieta hipercalórica. IIZD-UASLP. XXXVIII Presentación de conclusiones, avances y nuevas propuestas de Investigación. pp. 8. 16-18 dic. 2015.

[10] M.I. Días de Alba, J.A. Gestos Trojas, M.D. Granado Castro, M.D. Galindo Riaño y M.J. Casanueva Marenco. "Potencial uso de residuos agroalimentarios en la eliminación de metales contaminantes para la mejora del medioambiente". XLI Jornadas de Viticultura y Enología de la Tierra de Barros. I Congreso Agroalimentario de Extremadura. pp. 367-385. 2019.

[11] V.I. Valdez, B.J. Acevedo, and S.C. Hernández. "Distribution and potential of bioenergy resources from agricultural activities in Mexico". Renewable and Sustainable Energy Reviews. Vol. 14. pp. 2147-2153. 2010.

[12] J. M. Sánchez-Silva, R.R. González-Estrada, F.J. Blancas-Benitez y A. Fonseca-Cantabrana. "Utilización de subproductos agroindustriales para la bioadsorción de metales pesados". TIP Rev. Esp. en Ciencias Quim-Biol. Vol. 23. pp. 1-18. 2020.

[13] G. Yashni, A. Al-Gheethi, R. Maya Saphira R. Mohamed, V. A. Shanmugan, and J. A. Bakar. "Characterization of *Coriandrum sativum* leaves as a sustainable green biosorbent". Materials Today: Proceedings. 2021. In Press.

[14] N. Matic, V. Jena, D. Sinha, S. Ghosh, and A. Pandey. "Accumulation and Translocation of Heavy Metals in *Coriandrum sativum*". J. Appl. Chem. Vol. 8, No. 2. pp. 850-855. 2019.

[15] J.M. Vásquez Vásquez y K.J. Mera Livaque. "Disminución de los niveles de cadmio presentes en aguas residuales utilizando *Coriandrum sativum* (cilantro) en el laboratorio de biotecnología de la UCV -Chiclayo". Fondo Editorial de la Universidad César Vallejo. Trujillo, Perú. Primera edición. pp. 45. 2019.

[16] L. Kadiri, A. Lebkiri, E.H. Rifi, A. Ouass, Y. Essaadaoui, I. Lebkiri, and H. Hamad. "Kinetic studies of adsorption of Cu (II) from aqueous solution by coriander seeds (*Coriandrum Sativum*). E3S Web of Conferences. Vol. 37. pp. 1-7. 2018.

[17] R. Mehrandish, A. Rahimian, and A. Shahriary. "Heavy metals detoxification: A review of herbal compounds for chelation therapy in heavy metals toxicity". J. Herbmed. Pharmacol. Vol. 8, No. 2 pp. 69-77. 2019.

[18] R.A. Khan Rao and M. Kashifuddin. "Adsorption Properties of Coriander Seed Powder (*Coriandrum sativum*): Extraction and Pre-concentration of Pb(II), Cu(II) and Zn(II) Ions from Aqueous Solution". Adsorp. Scien. & Technol. Vol. 30 No. 2 pp. 1217-146. 2012.

[19] P.J. Boada Sánchez. "Estudio del proceso de biosorción de contaminantes en efluentes acuosos mediante cilantro (*Coriandrum sativum*). UC Ecuador. Facultad de Ingeniería Química. Carrera de Ingeniería Química. Tesis Licenciatura. Quito, Ecuador. 2015.

[20] A.E. Greenberg, L.S. Clesceri, and A.D. Eaton, "Standard Methods for the Examination of Water and Wastewater", American Public Health Association, Washington, DC, USA, 18th edition, 1992.

[21] R.P. Pantaler and I.V. Pulyaeva. "A spectrophotometric study of complexation between chromium and chromazurol S". J. of Anal. Chem. Vol. 40. pp. 1634-1639. 1985.

[22] M.E. Purata Díaz, A.S. Reyes Barbosa, P. Olivo Fat, J.F. Cárdenas González, A.S. Rodríguez Pérez, V.M. Martínez Juárez, M.E. Torre Bouscoulet, E. Enriquez Dominguez, and I. Acosta Rodríguez, "Removal of Chromium (VI) by the use of the residue of *Beta vulgaris* var. Cycla biomass". JMEST. Vol. 7, No. 11 pp. 13031-13035. 2020.

[23] V. Hernández López, M.M. Nájera Pérez J.F. Cárdenas González, V.M. Martínez Juárez e I. Acosta Rodríguez. Utilidad de la cáscara de aguacate (*Persea americana*) para la eliminación de Cromo (VI) de aguas contaminadas. TRANSV. CIENT. y TECNOL. Vol. 4 No. 1. pp. 110-117. 2020.

[24] H.T. Kahraman, and E. Pehlivan, "Cr^{6+} removal using oleaster (*Elaeagnus*) seed and cherry (*Prunus avium*) stone biochar", Powder Technol. Vol. 306. pp. 61–67. 2017.

[25] L.C. Maremeni, S. J. Modise, F.M. Mtunzi, M.J. Klink, and V.E. Pakade. "Adsorptive removal of hexavalent chromium by diphenylcarbazide-grafted *Macadamia* nutshell powder". Bioinor. Chem. Appl. Vol. 2018, Article ID 6171906, 14 pages. 2018.

[26] H. Ma, J. Yang, X. Gao, Z. Liu, X. Liu, and Z. Xu, "Removal of chromium (VI) from water by porous carbon derived from corn straw: Influencing factors, regeneration and mechanism". J. Hazard. Mater. Vol. 369. pp. 550-560. 2019.

[27] F.S. Huamani-Huashuayo and S.D. Quispe-Huamani. "Alternativa de remoción de cromo hexavalente a escala de laboratorio usando epicarpio de *Vitis vinifera* L." UPAS. Fac. Ciencias de la Salud. Carrera Prof. de Farmacia y Química. Arequipa, Perú. 2019.

[28] F. Liu, W. Zhang, L. Tao, B. Hao, and J. Zhang, "Simultaneous photocatalytic redox removal of chromium (VI) and arsenic (III) by hydrothermal carbon-sphere@nano-Fe_3O_4". Environ. Sci. Nano, Vol. 6. pp. 937-947. 2019.

[29] M. Taghi Ghaneian, M. Dehvari, and B. Jamshidi. "A batch study of hexavalent chromium removal from synthetic wastewater using modified Russian knapweed flower powder". Int. J. of Environ. Health Eng. Vol. 2, No. 5. pp. 38-46. 2013.

[30] I.F. Sarabia-Meléndez, M.S. Berber-Mendoza, O. Reyes-Cárdenas, M. Sarabia-Meléndez, and A. Acosta-Rangel, "Low cost biosorbents: An alternative treatment for contaminated water", Rev. Bio Ciencias Vol. 5, No. 1, pp. 1-15. 2018.

[31] Y. Huanga, X. Leeb, F.C. Macazo, M. Grattieric, R. Cai, and S. D. Minteerc. "Fast and efficient removal of chromium (VI) anionic species by a reusable chitosan-modified multi-walled carbon nanotube composite". Chem. Eng. J. Vol. 339. pp. 259-267. 2018.

[32] D. Pradhana, L.B. Suklaa, M. Sawyerb, and P. K.S.M. Rahman. "Recent bioreduction of hexavalent chromium in wastewater treatment: A review". J. Ind. and Eng. Chem. Vol. 55. pp. 1-20. 2017.

[33] G.S. Agarwal, H. Kumar, and S. Chaudari. "Biosorption of aqueous chromium (VI) by *Tamarindus indica* seeds". Bioresour. Technol. Vol. 97, pp. 949-956, 2006.

[34] I. Acosta Rodríguez, D. Alvarado Zamarripa, D.J. Sánchez Pérez, J.F., Cárdenas González, A.S. Rodríguez-Pérez, V.M. Martínez Juárez, J. Tovar Oviedo, and E. Enriquez Dominguez. "The use of *Cucumis sativus* shell biomass in the removal of Chromium (VI) in aqueous solution". JMEST. Vol. 7, No. 10. pp. 12907-12912. 2020.

[35] S.I. García, L. Candia, M.I. Frascaroli y J.C. González. "Sorción de cromo utilizando aquenio de *Platanus x hispánica".* Av. Cien. Ing. Vol. 9, No. 2. pp. 21-31. 2018.

[36] C. Cervantes, J. Campos, S. Devars, F. Gutiérrez, H. Loza, J.C. Torres, and R. Moreno, "Interactions of chromium with microorganisms and plants", FEMS Microbiol. Rev. Vol. 25, pp. 335-347, 2001.

[37] A.C. Landázuri, J.D. Cahuasquí, and A.S. Lagos. "Metal adsorption in aqueous media using *Moringa oleifera* Lam. seeds produced in Ecuador as an alternative method for water treatment". Av. Cien. Ing. Vol. 11, No. 17. pp. 190–205. 2019.

[38] N. Miranda Zea. "Biosorción de Cr (VI) de soluciones acuosas por la biomasa residual de hojas de eucalipto (G*lobulus labill*)". Rev. Did. de las Ciencias Nat. Vol. 1 No.1. pp. 20-32. 2019.