EVALUATION OF A CACTUS MUCILAGE BIOCOMPOSITE TO REMOVE TOTAL ARSENIC FROM WATER

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ABSTRACT

Mucilage fractions extracted from *Opuntia ficus-indica* cactus were captured in calcium alginate biobeads. The beads were tested as eco-friendly adsorbents to remove arsenic (As) from water, and their As removal efficiency was evaluated. Batch adsorption studies were performed using an incomplete factorial design by varying the concentrations of mucilage (0.5–2 mgL⁻¹), sodium alginate (3-5%), and calcium chloride (0.5-1 molL⁻¹) incorporated in the biobeads. The optimal formulation of these adsorbent biobeads varied depending on the mucilage fraction. Thus, biocomposite formulated with 1.25 mgL⁻¹ of gelling mucilage, 4% of sodium alginate, and 0.75 molL⁻¹ of calcium chloride eliminated up to 63% of As from water, with a capacity of 101.6 mgg⁻¹, whereas the composite biobeads formulated with 1.25 mgL⁻¹ of non-gelling mucilage reduced 59.8% of As from water, using the least amounts of sodium alginate and calcium chloride in the range tested, with a capacity of 97.1 mgg⁻¹.

Keywords: *Alginate; beads; arsenate; bioadsorption; adsorbent; wastewater.*

25 1. INTRODUCTION

26 Arsenic (As) is a ubiquitous heavy metal widely distributed in the environment. Its
27 toxicity, even at very low concentrations, may cause serious health hazards, increasing the
28 incidence of cancer and dermatological, vascular, and cerebrovascular diseases [1]. It is
29 estimated that 40 million people worldwide are at risk from drinking arsenic-contaminated
30 water [2,3].

31 Green technologies based on low-cost adsorbents from agricultural waste, industrial
32 by-product, or natural material currently are growing [4-7]. The literature includes various
33 works about the use of eco-friendly adsorbents based on lignocellulosic residues to eliminate
34 contaminants such as heavy metals and dyes from water [8-10]. These new materials involve
35 the ideal of Horizonte 2020 as “zero waste production” in the agro-industrial process.

36 In previous studies, it was found that cactus mucilage could be a potential complexant
37 of arsenic, although the separation of this mucilage-As complex from water was very
38 difficult [11]. Thus, it would be useful to design an efficient and heterogeneous contacting
39 system to allow easy separation of the mucilage-As complex. Moreover, it has been
40 demonstrated that eco-friendly adsorbents can be formulated by engulfing various materials
41 in calcium alginate beads to make commercially-viable, environmentally-benign, and
42 manageable adsorbents [12-16].

43 In the current study, different mucilage fractions were extracted from the
44 *Opuntia ficus-indica* cactus and engulfed in calcium alginate beads to formulate an eco-
45 friendly adsorbent to remove As from water allowing easy and efficient separation of the
46 mucilage-As complex from water. The formulation of this biocomposite was optimized using
47 an incomplete factorial design, and a morphological structure in the adsorbent was observed
48 using a Scanning Electron Microscope (SEM).

49 2. MATERIALS AND METHODS

50 **2.1. Extraction Process.** Pads of *Opuntia ficus-indica* cactus were obtained from our own set
51 of plants located in Tampa (Florida, USA) originally purchased from Living Stones Nursery
52 in Tucson Arizona, USA. Two fractions of the mucilage—non-gelling extract (NE) and
53 gelling extract (GE)—were extracted from the pads following the method described below.

54 **Non-Gelling Extract (NE).** The NE extract was obtained following the method
55 described by Goycoolea et al. [17] and modified by Buttice et al. [18] and Fox et al. [11]. The
56 liquid phase obtained from the previous step was filtered by vacuum pumping using a knitted
57 polyester cloth filter (Polx 1200, Berkshire Corp., Great Barrington, MA) and then
58 precipitated from the filtrate using an acetone 2:3 ratio of supernatant to solvent. The
59 precipitated NE extract was washed with ethanol–water solutions in a graded series (70%,
60 80%, 90%, and 95% ethanol and absolute ethanol) to remove the acetone and any remaining
61 impurities. The NE extract was left to dry at room temperature in a non-sealed, covered glass
62 container. After drying, the material was pulverized with a ceramic mortar and pestle and
63 stored in a closed container at room temperature.

64 **Gelling Extract (GE).** The extraction procedure to obtain the gelling extract (GE) was
65 an adaptation of a method developed by Turquois et al. [19] and modified by Buttice et al. [18]
66 and Fox et al. [11]. The modifications were made to improve the yield by centrifugation and
67 vacuum filtration using a different dosage of a chelating agent and a shorter sequestering time
68 compared with the original method and using acetone as the precipitating solvent. The solid
69 residue obtained in Step 1 of the mucilage extraction process was mixed with 7.5 gL^{-1} sodium
70 hexametaphosphate $[(\text{NaPO}_3)_6]$ in 50 mmolL^{-1} NaOH (1:1 mass-to-volume ratio of residue to
71 solution). The mixture was stirred for 1 hour and vacuum-filtered using a knitted polyester
72 cloth filter (Polx 1200, Berkshire Corp., Great Barrington, MA). The pH of the obtained
73 filtrate was lowered to 2.0 by titration with a hydrochloric acid solution 1 molL^{-1} and
74 refrigerated overnight (5°C) to precipitate the GE extract. The precipitate was separated by

centrifugation and re-suspended in sufficient DI water to cover it. The pH was adjusted to 8.0 with 1 mol L⁻¹NaOH to re-dissolve the precipitate. The resulting solution was purified by filtration through a 1.2 µm and a 0.45 µm membrane. The GE extract was re-precipitated with acetone in a 2:3 liquid-to-solvent ratio, then washed and dried at room temperature in a non-sealed covered glass container. After drying, the material was pulverized with a ceramic mortar and pestle and stored in a closed container at room temperature.

2.2. Elaboration of Cactus Mucilage Biocomposite. Cactus mucilage biocomposite was prepared following the procedure described by Vecino et al.[16] by mixing sodium alginate (3-5%) with cactus mucilage (0.5-2 mg L⁻¹), and the mixture solution was added to a calcium chloride solution (0.5-1 mg L⁻¹). Schematic representation of the cactus mucilage biocomposite preparation can be observed in **Figure 1**.

2.3. Morphological Characterization of Cactus Mucilage Biocomposite. Samples of the biocomposite were observed by SEM following the procedure described by Vecino et al.[16]. Detailed information about the characterization can also be found in the supporting information (SI).

2.4. Chemical Characterization of Cactus Mucilage Biocomposite by Attenuated Total Reflection Fourier Transform Infrared (ATR-FTIR). ATR-FTIR was used to characterize the functional groups of the two mucilage extracts, GE and NE. The analyses were carried out using a Nicolet 8700 spectrometer (Thermo Fisher, Madison WI, USA), collecting 300 scans in % transmittance mode. Mucilage films were prepared by adding 100 µL of a 5 g L⁻¹ mucilage suspension on top of a zinc selenide (ZnSe) crystal for use with a horizontal ATR accessory (Pike Technologies, Madison WI, USA). The suspension was allowed to air-dry for 24 hours before recording the spectra.

2.5. Box-Behnken Experimental Design. This experimental design is based on the use of mathematical and statistical tools for experiments based on a central point for building a

quadratic model that predicts the value of the dependent variable studied without needing to apply a completed three-level factorial design [20,21]. This model allows the development of empirical equations used to describe the behavior of dependent variables evaluated under different operational conditions (independent variables) in an established range. A quadratic function (**Equation 1**) is applied to adjust the experimental data obtained for the six dependent variables described in **Table 1**. Different coefficients will be obtained for each dependent variable studied (y). Detailed information about the experimental design can also be found in the SI.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 \quad (1)$$

The parameters included in **Equation 1** are defined as follows: y describes the elimination of As in water for different biocomposites formulated with the gelling or non-gelling fraction of cactus mucilage at different operational times; β are the regression coefficients obtained after the statistical analysis of the experimental results using the least-squares methodology; and x is the concentration of the coded independent variables studied (mucilage, calcium chloride, sodium alginate). The experimental values of the dependent variables were analyzed using Statistica 7.0 software (Statistica for Windows, StatSoft, Inc, USA) [15,16].

2.6. Batch Adsorption Experiments. Arsenic-rich aqueous solutions ($100 \mu\text{gL}^{-1}$) were prepared daily prior to the adsorption experiments. The experiments were carried out in 250 mL Erlenmeyer flasks using the cactus mucilage biocomposite formulated under different conditions (see **Table 1**). The liquid/solid ratio used during batch adsorption experiments was 1:0.5. The adsorption process was carried out at room temperature (25°C), and sample aliquots were removed from water at 5, 15, and 60 min. After that time, the percentage of As eliminated was quantified and used as a dependent variable for obtaining the optima

adsorbent conditions. In addition, the capacity of the gelling and non-gelling adsorbent was calculated after 60 min, as mg of As removed by g of cactus mucilage.

2.7. Analysis of Total Arsenic. Total As was analyzed by aHydride Generation–Atomic Fluorescence Spectrometrysystem(HG-AFS) on a PSA analytical 10.055 Millennium Excalibur instrument. Calibration standards were prepared from stock solutions diluted from high-purity standard solutions (1000 mg L⁻¹). In preparation for the analysis, the samples were combined with HCl and KI solutions to a final concentration of 30% of HCl and 2% of KI. Hydrochloric acid was added to provide excess H⁺ during the hydride generation, and KI was used to reduce the arsenic prior to the analysis.

3. RESULTS AND DISCUSSION

Water containing As was treated with two different fractions of mucilage entrapped in calcium alginate beads. The main components of the beads (mucilage, sodium alginate, and calcium chloride) were selected as independent variables to formulate the optimal composition of the biocomposite. The range of the dependent variables was fixed based on previous works, and sodium alginate and calcium chloride were used to immobilize different adsorbents consisting of activated carbon or peat[12-16]. **Table 1** shows the independent and dependent variables studied. Two experimental designs were carried out. In the first, the biocomposite was formulated using the non-gelling fraction of cactus mucilage, and in the second, the biocomposite was formulated using the gelling fraction of cactus mucilage. For comparative purposes, in both designs the ranges of concentration of the gelling and non-gelling mucilage, as well as the other independent variables (sodium alginate and calcium chloride), were the same.

Table 2 shows the experimental conditions used and the results obtained for the dependent variables studied. Variables y_1 to y_3 correspond with the first design (gelling

fraction of mucilage was used), and variables y_4 to y_6 correspond with the second design (non-gelling fraction of the mucilage used during the biocomposite formulation).

3.1. Formulation of Biocomposite Containing the Gelling Fraction of Cactus

Mucilage. The complete set of data concerning the normalized, dimensionless operational variables as well as the results determined for the dependent variable studied concerning to the biocomposite formulated with the gelling fraction of cactus mucilage (variables y_1 to y_3) are listed in **Table 2**. The elimination rate of As from water was evaluated at different times. As the set of experiments has an incomplete, centered, factorial structure with replications in the central point of the experimental domain, the dependent variables concerning the formulation of biocomposite containing gelling mucilage can be calculated as the contribution of linear, interaction, and second-order terms according to **Equation 1**. The regression coefficients and their statistical significance for variables y_1 to y_3 are listed in **Table 3**. From the absolute value and significance of the coefficients listed in **Table 3** corresponding to variable y_3 , it can be deduced that the concentration of gelling mucilage (x_1) and sodium alginate (x_2) have a significant effect on the elimination of total As from water, whereas the calcium chloride concentration (x_3) showed a significant effect only when taking into account the interaction of x_2 with x_3 .

Using **Equation 1**, various empirical models can be developed to predict the As elimination rate in the range tested for variables y_1 to y_3 . On the basis of the significance for each coefficient, measured as p -values, it was observed that at higher adsorption times, more significant coefficients were obtained (see **Table 3**).

Experimental results showed that the maximum removal rate of As from water was obtained when contaminated water was treated with biocomposite formulated with intermediate concentrations of gelling mucilage, sodium alginate, and calcium chloride (see **Table 2**). Thus, when coded independent variables were fixed at intermediate conditions

(0,0,0), about 63% of As was eliminated from water after 60 min of treatment. This result is in concordance with that predicted by the empirical model. Using **Equation 1**, an empirical model can be developed to predict the As elimination rate in the range tested. Thus, under intermediate conditions, the model predicts that 63.3% of As can be eliminated from water, indicating good agreement between experimental and theoretical data.

It is important to point out that the elimination of As from water using this novel biocomposite containing the gelling fraction of cactus mucilage occurs very quickly. Therefore, after 5 min of treatment, experiment data showed that the biocomposite formulated under different conditions removed between 40.7% and 52.2% of As (see **Table 2**), respectively, obtaining maxima elimination rates of As when the independent variables were fixed at intermediate concentrations in the range tested. At these optima formulation conditions, the adsorption capacity for the alginate-gelling mucilage biocomposite was 101.6 mg g^{-1} (at 60 min).

Figure 2 shows the variation of As reduction in water with the amount of gelling mucilage (x_1) and sodium alginate (x_2), fixing the calcium chloride concentration (x_3) at intermediate values. These data also corroborate that the maximum reductions of As were obtained when the independent variables were fixed at intermediate values. After 5 min of treatment, the model predicts that it is possible to remove up to 48.5% of As (**Figure 2a**), whereas after 15 min and 60 min of adsorption treatments, the model predicts that 54.3% and 62.0% of As can be eliminated from water, respectively (see **Figures 2b** and **2c**). These results are in concordance with those obtained experimentally. Moreover, the regression coefficient values, r^2 , were 0.90, 0.75, and 0.94 for y_1 , y_2 , and y_3 , respectively.

In previous works [11], the gelling extract of cactus mucilage was able to complex 14% of As from water, whereas in the current work this gelling extract entrapped in calcium alginate beads was able to remove up to 63% of As from water. Moreover, the cactus

mucilage biocomposite-As complex was easily separated from the aqueous phase by a simple filtration.

3.2. Formulation of Biocomposite Containing Non-Gelling Fraction of Cactus

Mucilage. Concerning the elimination of As using biocomposite formulated with the non-gelling fraction of cactus, **Table 2** shows the experimental results achieved using the normalized, dimensionless operational variables, and **Table 3** shows the coefficients and the significance of each (*p*-values) for the variables y_4 to y_6 . As in the previous design, concerning the gelling fraction of cactus mucilage, it is, therefore, possible to calculate the As eliminated by the biocomposite containing the non-gelling fraction of cactus. No significant coefficients (i.e., $p > 0.05$) can be eliminated from the equations. From the absolute value and significance of the coefficients obtained for variables y_4 to y_6 , it can be deduced that the concentration of non-gelling mucilage is the most significant independent variable.

On the other hand, **Table 2** shows that the maximum experimental As reduction in water (59.8%) was achieved when the biocomposite was formulated with intermediate concentration of mucilage (1.25 mgL^{-1}) and the lowest concentration of sodium alginate (3%) and calcium chloride (0.5 molL^{-1}). Under these experimental conditions, the model predicts that 59.1% of As can be eliminated. As can be observed, the model predicts a good correlation between the experimental and theoretical data. At optimal conditions, the adsorption capacity for the alginate-non-gelling mucilage biocomposite was 97.1 mgg^{-1} (at 60 min).

These results are higher than those obtained with the non-gelling fraction of cactus mucilage. Thus, when this mucilage fraction was added into the contaminated water, 9% of As was entrapped by this mucilage [11], indicating, in this case, that the immobilization of the non-gelling fraction of cactus mucilage in calcium alginate beads also increases the capacity of the adsorbent to eliminate As from water.

For comparative purposes, **Figure 3** shows the variation in the elimination rate of As with the non-gelling mucilage (x_1) and sodium alginate (x_2), fixing the calcium chloride concentration (x_3) at intermediate values after 5 min (**Figure 3a**), 15 min (**Figure 3b**), and 60 min (**Figure 3c**) of treatment. Thus, using the biocomposite formulated at intermediate conditions (0,0,0), the model predicts that 43.8%, 44.7%, and 56.1% of As can be eliminated from water after 5 min, 15 min, and 60 min, respectively, of treatment with this novel adsorbent containing the non-gelling fraction of cactus mucilage. The regression coefficients values, r^2 , were 0.86, 0.74, and 0.85 for y_4 , y_5 , and y_6 , respectively.

In comparison with other works, Pant and Airee[22] eliminated up to 84% of As from water using low-cost materials (rusted iron, nails, charcoal, brick pieces, pebbles, and sand). The elimination rate was higher than that obtained in the present work, but it is necessary to take into account that Pant and Airee[22] used a maximum concentration of As in water of 57 $\mu\text{g.L}^{-1}$, whereas the initial concentration of As in the current work was 100 $\mu\text{g.L}^{-1}$. Thus, the capacity of the adsorbent based on cactus mucilage entrapped in calcium alginate beads is higher than the adsorbent based on low-cost materials packed in plastic buckets.

Moreover, Nigam et al.[23] used 1 g of herbal dye waste to remove 30–50% of arsenic after 60 min from aqueous solution in which the initial concentration of As was 500 $\mu\text{g.L}^{-1}$.

On the other hand, Medina et al., [24] proposed zeolite and zeolite modified with NH_4Cl and aluminium sulfate to eliminate As from water. Zeolite alone removed 8% of As from an initial concentration of 740 $\mu\text{g.L}^{-1}$ after 8 hours of treatment, whereas zeolite modified with aluminium sulfate was able to reduce the As concentration of water from 740 $\mu\text{g.L}^{-1}$ to 10 $\mu\text{g.L}^{-1}$ after 5 min of treatment.

In addition, Rahman et al., [25] used iron-oxide coated sand (IOCS) to treat water containing 740 $\mu\text{g.L}^{-1}$ of As. In this case, iron-oxide-coated sand eliminated 75% of As after 15

min of treatment, and Gupta et al., [26] used chitosan-coated sand (CCS) to reduce 500 $\mu\text{g L}^{-1}$ of As to 10 $\mu\text{g L}^{-1}$ after 2 h of treatment.

In some cases, the amount of As eliminated from water is important, as in using aluminium sulfate zeolite. However, it is necessary to take into account that the use of aluminium for the treatment of water is not recommended because it has been demonstrated that aluminium may have toxicological effects on human health [27,28]. Moreover, many of the adsorbents proposed in the literature have several disadvantages, such as difficult handling and ability to clog membranes, whereas the biocomposite proposed in this work can easily be separated from water, regenerated, and stored for future reuse.

3.3. Morphological Characterization of Cactus Mucilage Biocomposite. Figure 4a and Figure 4b show comparative SEM images of cactus mucilage biocomposite composed by the gelling and non-gelling fraction of cactus mucilage, respectively, and formulated under the optima conditions predicted by the model (1.25 mg L^{-1} of mucilage, 3% of sodium alginate and 0.5 mol L^{-1} of calcium chloride). Figures 4a (1 to 3) show the external morphology of biocomposite formulated with the gelling fraction of cactus mucilage at different magnifications of $\times 30$, $\times 1000$, and $\times 5000$; Figures 4b (1 to 3) show the external morphology of biocomposite formulated with the non-gelling fraction of cactus mucilage at $\times 30$, $\times 1000$, and $\times 5000$ magnifications. It can be observed that biocomposite formulated by the non-gelling fraction of cactus mucilage is rougher than the biocomposite formulated using the gelling fraction of cactus.

On the other hand, Figure 4a (4 to 6) shows the internal composition of beads containing the gelling fraction of cactus mucilage after a transversal cut at different augmentations ($\times 43$, $\times 5000$, and $\times 25000$, respectively); Figure 4b (4 to 6) shows the internal composition of beads containing the non-gelling fraction of cactus mucilage at $\times 33$, $\times 5000$, and $\times 25000$ augmentations. Comparing the images shown in Figure 4a (5 and 6) with the

images shown in **Figures 4b (5 and 6)**, it can be observed that biocomposite formulated with the gelling fraction of cactus mucilage is composed of a higher degree of microporosity than that observed in the biocomposite containing the non-gelling fraction of cactus mucilage. This fact can suppose a higher adsorption surface area for the biocomposite containing the gelling fraction of cactus mucilage. This finding is in concordance with the results obtained in this work, where the inclusion of the gelling fraction in the biocomposite gave slightly better results than that achieved with the non-gelling fraction of cactus mucilage.

These results also corroborate with Buttice et al. [18] where structural differences between the two extracts of the mucilage, GE and NE, were associated with a slightly better performance of the GE extract to remove *Bacillus cereus* from water.

3.4. Chemical Characterization of Cactus Mucilage Biocomposite by ATR-FTIR. The main absorbance bands present in the GE and NE extracts are presented in the **Figure 5**. The ATR-FTIR spectra of GE and NE are very similar and corroborate with the results from Fox et al. [11]. Some differences between the GE and NE spectra can be observed, and those might be associated with the difference in the performance of the two extracts. A more prominent peak associated with CH stretching at $2918\text{--}2920\text{ cm}^{-1}$ is present on the NE spectrum, as well as the presence of carbonyl C=O stretch at 1725 cm^{-1} that is absent in GE spectrum. NE spectrum also presents an intense band associated with HC–O–H stretch of cyclic alcohols at 1041 cm^{-1} , where the GE shows bands at 1100 and 1018 cm^{-1} correlated with the uronic acid content of pectic polysaccharides.

The mechanism of interaction between the mucilage extracts and As in solution proposed by Fox et al. [11] may also explain the removal of As by the biocomposites studied in the present work. Hydrogen-bonded bridging between the protons associated with the As species and the ionized hydroxyl, carboxyl, and carbonyl groups on the mucilage are binding the As into the biocomposites and removing the As from the water.

4. CONCLUSIONS

In this work, a new eco-friendly and low-cost adsorbent based on cactus mucilage entrapped in calcium alginate beads has been developed for the elimination of total As from water. The biocomposite formulated with 1.25 mgL⁻¹ of gelling mucilage, 4% of sodium alginate, and 0.75 molL⁻¹ of calcium chloride was able to remove up to 63% of As from water, with a capacity of 101.6 mgg⁻¹, whereas the composite biobeads formulated with 1.25 mgL⁻¹ of non-gelling mucilage using the same amounts of sodium alginate and calcium chloride were able to reduce 59.8% of As from water, with a capacity of 97.1 mgg⁻¹. Performance differences may be related with chemical and morphological characteristics of the mucilage extracts. In both cases, the biocomposite formed stable beads with a high capacity to adsorb As from water. Moreover, the mucilage biobeads proposed in this work are easy to handle and do not clog membranes, thus encouraging their use, regeneration, and storage.

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Notes

The authors declare no competing financial interest.

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LIST OF TABLES

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Table 2. Operational conditions considered in this study (expressed in terms of coded independent variables) and experimental results achieved for dependent variables y_1 to y_6 .

Table 3. Regression coefficients and their statistical significance for variables y_1 to y_6 .

TABLE 1

<i>a) Independent variables</i>			
Variable	Nomenclature	Units	Range of variation
Mucilage	M	mg L ⁻¹	0.5-2
Sodiumalginate	A	%	3-5
Calciumchloride	C	mol L ⁻¹	0.5-1
<i>b) Dimensionless, coded independent variables</i>			
Variable	Nomenclature	Definition	Range of variation
Dimensionless mucilage	x ₁	$([M] - 1.25)/0.75$	(-1,1)
Dimensionless sodium alginate	x ₂	$([A] - 4)/1$	(-1,1)
Dimensionless calcium chloride	x ₃	$([C] - 0.75)/0.25$	(-1,1)
<i>c) Dependent variables</i>			
Variable	Nomenclature	Units	
GE after 5 min	y ₁	%	
GE after 15 min	y ₂	%	
GE after 60 min	y ₃	%	
NE after 5 min	y ₄	%	
NE after 15 min	y ₅	%	
NE after 60 min	y ₆	%	

TABLE 2

Independent variable				Dependent variable					
Exp.	x ₁	x ₂	x ₃	y ₁	y ₂	y ₃	y ₄	y ₅	y ₆
1	0	-1	-1	50.1	53.1	58.1	42.1	45.7	59.8
2	0	1	-1	42.6	48.6	60.4	47.9	49.0	59.0
3	0	-1	1	45.4	53.5	63.6	44.6	44.5	56.8
4	0	1	1	43.7	46.2	52.7	42.1	47.3	56.2
5	-1	-1	0	41.7	50.1	56.7	40.8	41.5	52.2
6	-1	1	0	40.7	47.8	52.0	39.8	38.6	49.7
7	1	-1	0	43.6	48.3	54.8	43.2	44.0	52.5
8	1	1	0	42.9	46.8	53.8	41.0	43.2	49.9
9	-1	0	-1	48.8	47.8	56.2	38.0	42.6	49.0
10	-1	0	1	44.7	53.4	59.2	42.4	43.7	52.2
11	1	0	-1	49.0	53.4	57.5	41.8	43.5	54.8
12	1	0	1	49.8	58.0	61.7	39.7	41.8	54.9
13	0	0	0	52.2	55.0	63.2	43.3	42.1	54.0
14	0	0	0	48.2	56.5	64.0	42.3	43.5	55.3
15	0	0	0	48.1	54.5	62.7	42.8	42.0	56.0

TABLE3

	y ₁	p _{y1}	y ₂	p _{y2}	y ₃	p _{y3}	y ₄	p _{y4}	y ₅	p _{y5}	y ₆	p _{y6}
b ₀	49.50	0.00074*	55.33	0.00012*	63.30	0.00004*	42.80	0.00005*	42.53	0.00013*	55.10	0.00011*
b ₁	1.18	0.29121	0.93	0.12847	0.46	0.18420	0.59	0.07985	0.76	0.12376	1.13	0.08844
b ₁₁	-2.33	0.19629	-2.14	0.05842	-4.51	0.00567*	-2.65	0.00950*	-2.22	0.03665*	-4.63	0.01279*
b ₂	-1.36	0.24117	-1.95	0.03382*	-1.79	0.01641*	0.01	0.95006	0.30	0.41814	-0.81	0.15183
b ₂₂	-4.95	0.05548	-4.94	0.01180*	-4.46	0.00580*	1.05	0.05628	1.51	0.07449	0.60	0.37375
b ₃	-0.86	0.40643	1.03	0.10834	0.63	0.11446	-0.13	0.55279	-0.44	0.27806	-0.31	0.47563
b ₃₃	0.90	0.53666	-0.04	0.94569	-0.14	0.72600	0.33	0.33803	2.58	0.02738*	2.25	0.05093
b ₁₂	0.08	0.95470	0.20	0.73776	0.93	0.10603	-0.30	0.35300	0.53	0.33714	-0.03	0.96518
b ₁₃	1.23	0.40478	-0.25	0.67837	0.30	0.45679	-1.63	0.02286*	-0.70	0.23699	-0.78	0.26626
b ₂₃	1.45	0.34074	-0.70	0.31083	-3.30	0.00973*	-2.08	0.01421*	-0.13	0.79375	0.05	0.93050

* Significant coefficients (p<0.05).

FIGURE CAPTIONS

Figure 1. Flowchart of the cactus mucilage biocomposite preparation.

Figure 2. Dependence of a) GE after 5 min (y_1), b) GE after 15 min (y_2), c) GE after 60 min (y_3), with mucilage and sodium alginate, at intermediate concentration of calcium chloride.

Figure 3. Dependence of a) NE after 5 min (y_4), b) NE after 15 min (y_5), c) NE after 60 min (y_6), with mucilage and sodium alginate, at intermediate concentration of calcium chloride.

Figure 4. SEM micrographs of a) GE biocomposite and b) NE biocomposite.

Figure 5. ATR-FTIR spectra of the mucilage extracts, GE and NE. Major bands correspond to OH (3284 and 3315 cm^{-1}), CH (2920 and 2918 cm^{-1}), COO- (1624 , 1619 , 1412 and 1408 cm^{-1}), N-H (1538 cm^{-1}), and CO from secondary alcohol (1041 cm^{-1}) groups.

FIGURE 1

FIGURE 2

FIGURE 3

a) GE biocomposite

b) NE biocomposite

FIGURE 4

FIGURE 5

Graphical Abstract

Biocomposite – Arsenic Complex