

CELLULOSIC MEMBRANES SUPPORTED WITH SILICA FROM RICE HUSK AND RICE HUSK ASH FOR SLOW RELEASE**Francine Gastaldon^{a,b}, Eduardo Junca^a, Felipe Fardin Grillo^c, Antônio Carlos Sobieranski^d, Suzane Quintana Gomes^b, Jamal Rafique^e, Tatiana Gisset Pineda Vásquez^f and Tiago Elias Allievi Frizon^{b,*}**^aPrograma de Pós-Graduação em Ciência e Engenharia de Materiais (PPGCEM), Universidade do Extremo Sul Catarinense (UNESC), 88806-000 Criciúma – SC, Brasil^bDepartamento de Energia e Sustentabilidade, Universidade Federal de Santa Catarina (UFSC), Campus Araranguá, 88906-072 Araranguá – SC, Brasil^cPrograma de Pós-Graduação em Engenharia Metalúrgica e de Materiais (PROPEMM), Instituto Federal do Espírito Santo, 29040-780 Vitória – ES, Brasil^dDepartamento de Computação, Universidade Federal de Santa Catarina (UFSC), Campus Araranguá, 88906-072 Araranguá – SC, Brasil^eInstituto de Química, Universidade Federal do Mato Grosso do Sul, 79074-460 Campo Grande – MS, Brasil^fFaculdade de Química Industrial, Instituto Tecnológico Metropolitano (ITM), 050034 Medellín, Colômbia

Received: 06/11/2024; accepted: 11/21/2024; published online: 01/09/2025

The aim of this work was to study silica extraction from rice husk (RH) and rice husk ash (RHA). Bacterial cellulose (BC) was used to transport the extracted silica as well as the slow-release silica material. The silica extraction from RH and RHA was performed by leaching using ultrapure water and NaOH. Silica was quantified by UV-Vis spectrophotometer. BC membranes were produced with *Komagataeibacter hansenii*. Then, the membranes were impregnated with silica-rich leached extracts. Silica release tests under controlled conditions were conducted. Characterization of the impregnated membranes was conducted by Fourier transformed infrared spectrometry (FTIR), microstructural (scanning electron microscopy (SEM)) and mechanical resistance analyses. The results indicated that the RH and RHA leachates from the extractor solution containing NaOH contained more silica than did the extracts from ultrapure water. The BC membranes supported with the aqueous extract of RH released 58% of the adsorbed silica in 24 h. The BC membranes impregnated with RHA-H₂O released 67% of the silica. The silica release reached 62% for RH and 60% for RHA from the extract leached with NaOH. The membranes showed a high capacity to retain both water and silica, which can be an alternative to reduce economic losses due to solubilization of fertilizers in the agricultural sector.

Keywords: rice husk; rice husk ash; silica; cellulosic membrane; controlled release.

INTRODUCTION

According to Channab *et al.*,¹ the demand for fertilizers reached 203 million metric tons of nutrients in 2023. This high consumption of fertilizers and the trend of population growth, with approximately 10 billion people in 2050,² raise concerns regarding the lack of this input. Beyond the greater future demand for fertilizers, the low efficiency of currently used fertilizers exacerbates this problem. Yang and co-workers³ mentioned that conventional chemical fertilizers normally have an efficiency between 30 and 50%, which results in economic losses and soil pollution. To support population growth, food production is expected to increase by 70%.⁴

Specifically, the use of silicon (Si) to alleviate biotic and abiotic stress as well its use as a fertilizer on crop, is well-known. Due to its particular characteristics, such as noncorrosive, pollution-free nature, inexpensive, capacity to soil pH correction, etc., evokes the idea of a friendly and sustainable fertilizer source.⁵⁻⁷ Moreover, Si is essential for plant physiology and biochemistry acting in the absorption of nutrients and water retention, protecting the stress signaling pathways.⁸

It is worth noting that, despite Si being the second most abundant element in the soil, its low solubility compromises its availability to plants.⁵ Nevertheless, advanced technologies such as slow and controlled release fertilizers and superabsorbent hydrogels are

promising for maximizing nutrient availability in the soil. In this context, bacterial cellulose is a superabsorbent material that can be used as a fertilizer carrier.⁹ This material has the potential to be applied as a nutrient transport medium as well as a controlled release product.

Brazil is one of the largest rice-producing countries in the world. According to Schwanke *et al.*,¹⁰ between 2021 and 2022, 11,792 thousand tons of rice were produced in Brazil. It is estimated that for each ton of rice, 0.2 tons of rice husk (RH) are generated,¹¹ which shows great potential for the study and value of this material. Grotto *et al.*¹² reported that the content of volatile materials in rice husk ranged from 64.86 to 88.1 wt.%, and the ash content ranged from 6.90 to 23.84 wt.%. The composition of the ash rice husk depends on climatic conditions and geographical characteristics. However, it is known that rice husk ash has a high content of silica. Fernandes *et al.*¹³ determined that the content of silica in rice husk ash (RHA) was 96.73 wt.%, and Camargo-Perez *et al.*¹⁴ determined that the RHA contained 80.7 wt.% silica. Thus, rice husk ash can be a potential source of silica for fertilizer.

Several studies have been conducted to valorize rice husk and rice husk ash, such as fuel,¹⁵⁻¹⁷ filler in asphalt mixtures,¹⁴ concrete,¹⁸⁻²⁰ sorbent material,²¹ and silica production.^{13,22,23} Thus, few studies have investigated the use of rice husk and rice husk ash to supply silica as fertilizers. Therefore, the objective of this work was to study the extraction of silica from rice husk and rice husk ash. Furthermore, this work also aimed to use bacterial cellulose as a means of transporting extracted silica and as a slow-release silica material.

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Associate Editor handled this article: Eduardo H. S. Sousa

EXPERIMENTAL

Materials

For silica extraction, 10 g of RH and RHA samples, 250 mL of ultrapure water (Milli-Q), and sodium hydroxide solution (10 g L⁻¹) were used. The bacterium *Komagataeibacter hansenii*, strain ATCC 23769, from the “Tropical Culture Collection”, was used to produce the bacterial cellulose.²⁴ Bacterial cellulose was cultivated in Schramm’s Hestrin media, which was composed of glucose (20.0 g L⁻¹), peptone (5.0 g L⁻¹), yeast extract (5.0 g L⁻¹), anhydrous sodium bibasic phosphate (2.7 g L⁻¹) and monohydrate citric acid (1.15 g L⁻¹).

Methods

Both the rice husk (RH) and the rice husk ash (RHA) come from a rice processing industry located in the municipality of Turvo in the extreme south of Santa Catarina. At the grain processing plant, the husk is burned to heat the boilers, reaching temperatures of up to 600 °C. In this process, rice husk ash is generated as a byproduct of the energy processing. At no time did either residue used to carry out the experiments undergo any type of preliminary treatment or purification.

The leaching step occurred via two methods. First, leaching was carried out with ultrapure water. In the second method, leaching was performed with NaOH solution. According to Haq *et al.*,²⁵ the ideal concentrations of hydroxide for the extraction of SiO₂ is up to 1 M. Beyond these values, the extraction becomes economically unviable, since for small increases in the concentration of NaOH, the percentage of recovery of SiO₂ is insignificant, so it was decided to proceed the experiments using 0.1 M. In both methods, the liquid/solid ratio was 1:20 (m/v).

The mass of RH or RHA was transferred to a beaker containing NaOH solution. Then, the mixture was agitated with stirring at 30 ± 2 rpm for 24 h at 25 °C and filtered. Then, the samples were dried in a furnace at 105 °C for 24 h and weighed to determine the solid content obtained from the leaching process. The pH of the RH- and RHA-leached extracts was determined using a pH meter.

The content of leached silica was determined by UV-Vis spectrometry, and a silica standard curve was generated at a wavelength of 660 nm. To determine the content of silica in the leached solution, an aliquot of 2.5 mL was collected. Then, 0.1 mL of ammonium molybdate solution (0.1 g mL⁻¹) and 0.05 mL of 1 M HCl were added to the aliquot. The solution was manually stirred and then kept at rest for 5 min. Afterwards, 0.1 mL of oxalic acid solution (3 g L⁻¹) was added to the solution to change the color from yellow to blue. The samples were placed in quartz cuvettes, and the set was analyzed in a UV-Vis spectrophotometer with a range of 190 to 1100 nm and a bandwidth of 2 nm.

Fourier transform infrared spectrometry (FTIR) analyses were performed in the RH and HRA before and after the leaching process with a spectral range from 4000 to 400 cm⁻¹ and a resolution of 4 cm⁻¹ using the IRSpirit T Shimadzu equipment and attenuated total reflectance (ATR) technique.

The culture of the bacterium *Komagataeibacter hansenii* (strain ATCC 23769) was carried out in Schramm’s Hestrin medium, with the pH adjusted to 6.6 with the aid of HCl and NaOH solutions, followed by sterilization in an autoclave at 121 °C for 20 min. The sterilized culture medium was cooled to 30 °C, and 5% of the previously prepared inoculum was added and maintained under these static conditions in an incubator. After 15 days of cultivation, the hydrogel-shaped membrane and the liquid surface were separated, washed with distilled water, and purified using a 0.1 M NaOH solution for 24 h to

remove bacterial impurities and possible contaminants. The samples were washed with deionized water until reaching neutral pH (7.0) and stored in a 20% ethanol solution.

The mechanical resistance analysis verified the tensile mechanical behavior of the BC membranes containing silica. The tensile strength was measured using a TA HD plus texture analyzer. The test occurred at room temperature at a pulling speed of 1 mm min⁻¹.

Silica adsorption

The adsorption of silica occurred through the immersion of the BC membrane in 25 mL of extraction solution under constant stirring (30 ± 2 rpm) at 25 °C for 24 h. The 0.1 M NaOH leachate samples were diluted (1:1 v/v) because they exceeded the UV-Vis absorption values.

Membrane characterization

To obtain images of the BC membranes JEM-1011 Scanning Electron Microscope (SEM) from Laboratório Central de Microscopia Eletrônica (UFSC) was used. All BC membranes were immersed for 7 days in the solutions with the extracted SiO₂ and thus achieved saturation with silica.

Water absorption

The water absorption percentage (WA %) of the bacterial cellulose membrane was evaluated using the gravimetric method. The membranes containing silica were dried in a furnace for 24 h at 105 °C. Then, they were weighed and subsequently hydrated for 24 h. Then, the membrane was weighed, and the amount of water absorbed was calculated according to Equation 1.

$$WA \% = \frac{WSW - DSW}{WSW} \times 100 \quad (1)$$

where WSW is the wet sample weight (g) and DSW is the dry sample weight (g).

Ion exchange capacity (IEC)

The ionic exchange capacity of the BC after functionalization was determined by the potentiometric titration method. This method consists of the proton exchange capacity present in the dry mass of BC (acid form) necessary to neutralize an equivalent quantity of base. For this purpose, membrane samples of BC and BC/SiO₂ were immersed in a 1 M NaCl solution for 48 h and after immersion in the leached solutions, the membranes of BC were dried in 105 °C oven for 24 h.

A 0.005 M sodium hydroxide (NaOH) solution was used to perform the titration of the NaCl solution after proton exchange, using phenolphthalein as an indicator and the reference electrode used was a benchtop pH meter. The IEC was calculated using Equation 2.²⁶

$$IEC = \frac{VTA [TA]}{\text{Membrane mass}} \quad (2)$$

where VTA is the volume of the titrant agent, in L, and [TA] is the concentration of the titrant agent, in mol L⁻¹.

Silica release test

The release rate of SiO₂ from the BC membrane was determined using a water extraction solution with 0.01 M citric acid following a

methodology adapted from that reported by Lateef *et al.*²⁷ In different Erlenmeyer flasks, 1.0 g of each sample (BC membrane containing adsorbed silica) was mixed in 10 mL of citric acid aqueous solution (solid:extractant ratio of 1:10). The mixture was allowed to rest for 2 h, 8 h, 16 h, 24 h, 7 days, or 15 days. At each contact time, an aliquot of 3 mL was collected. The percentage of silica was determined using an automatic UV-Vis spectrophotometer with a UV-Vis range of 190 to 1100 nm and a bandwidth of 2 nm.

RESULTS AND DISCUSSION

Silica extraction and FTIR characterization

Experiments showed that concentration of SiO₂ present in the RH was 85% and in the RHA was 91%. Table 1 shows the results of silica extraction from RH and RHA in ultrapure water and NaOH solution and the correspondent percentage of extracted silicon. The concentrations of RH and RHA used for silica extraction from ultrapure water reached 14 and 3 mg L⁻¹, respectively. The silica concentration extracted with NaOH solution was 4251 mg L⁻¹ for rice husk leached (RHL) and 6825 mg L⁻¹ for rice husk leached ash (RHAL).

Table 1. Silica extraction from RH and RHA in ultrapure water and NaOH solution

Sample	Leaching medium	SiO ₂ concentration / (mg L ⁻¹)	SiO ₂ / %
RH	ultrapure water	14 ± 1	0.2
RH	NaOH	4251 ± 227	50
RHA	ultrapure water	3 ± 1	0.03
RHA	NaOH	6825 ± 3	75

RH: rice husk; RHA: rice husk ash. Source: Authors.

Compared with the RHAL in ultrapure water, the RH samples showed a greater concentration of silica. The pH values of the RH leachate in ultrapure water ranged between 6.4 and 6.7. For the sample containing the NaOH solution, the pH was 13.2. For the RHAL, the pH varied between 8.4 and 9.0 for the ultrapure leaching solution and remained unchanged at 13.2 for the NaOH solution.

Figure 1 shows the absorption spectra of the IR region of RH and RHA, and RHL and RHAL with ultrapure water and NaOH. In the region of 1040-1061 cm⁻¹, there is an intense band attributed to the asymmetric stretching of the Si–O–Si bond, which is more intense in the RHA spectra. At 798 cm⁻¹ a band of lower intensity is observed, which is related to the symmetric stretching of this same bond. Through the analysis of the FTIR spectra, the RHA samples present the most intense signals related to the presence of silica, due to the high silica content remaining when rice husk is burned, indicating the presence of more silica than other components of the sample as attested by Fernandes *et al.*¹³ and Camargo-Perez *et al.*¹⁴ This result corroborates the results obtained in the silica quantification stage using a UV-Vis spectrophotometer.

Synthesis of bacterial cellulose membrane

In order to study the capacity of silica release from bacterial cellulose membrane, we synthesized a hydrogel-shaped membrane based on a culture of the bacterium *Komagataeibacter hansenii*. The bacterial cellulose (BC) membrane synthesized is shown in Figure 2.

The functionalization of BC membrane was performed by immersing the BC membrane in 25 mL of extraction solution of RH

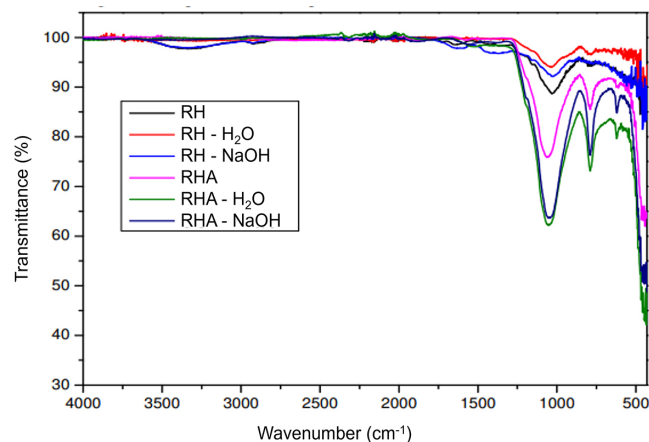


Figure 1. FTIR (ATR) spectra for samples RH, RHA, RHL and RHAL



Figure 2. Image of the bacterial cellulose (BC) membrane (source: authors)

and RHA under constant stirring at 25 °C for 24 h. The next step was to obtain the images of the four BC membranes by scanning electron microscopy. Figure 3e revealed a fibrillar structure typical of bacterial cellulose,²⁸ which was partially lost as showed in Figures 3c and 3d. It is possible to observe the presence of silica particles adhered to the fibrillar structure of the BC membranes, mainly in both membranes that NaOH was used as an extracting agent (Figures 3c and 3d). The size of the particles ranged from 0.5 to 1 μm because of the extraction of RH and RHA from water (Figures 3a and 3b). Figures 3c and 3d show that silica particles with an ellipsoidal shape and uniform sizes varying between 0.3 and 0.4 μm can be observed for those resulting from extraction with NaOH. Figure 3e corresponds to the bacterial cellulose membrane before functionalization.

The water absorption (Table 2) of the silica-functionalized BC membranes indicated a maximum absorption of 3.6% for BC when NaOH solution was used as the leaching agent. This percentage of water retention was lower for membranes in which the fibrillar structure was partially lost, as observed in Figure 3.

Table 3 shows the results of the modulus of elasticity and maximum tension for pure and functionalized BC membrane. The samples did not show differences in relation to the elastic modulus, as the standard deviation is within the margin of error. However, all the functionalized BC showed significant dispersion, with a more pronounced effect on the samples from NaOH extraction.

The presence of silica in the samples modified the elastic modulus of BC, so that all samples exhibited a decrease in tensile strength. The presence of silica affects the free OH groups present in the hydrogen

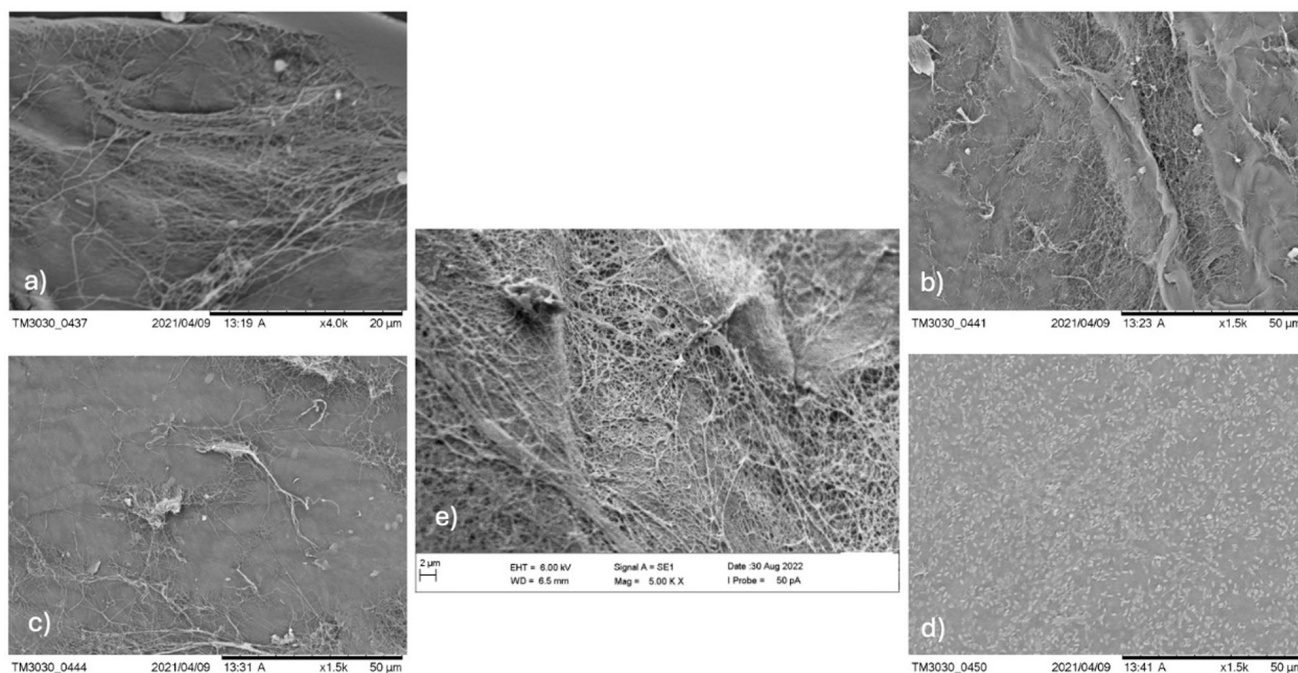


Figure 3. SEM images of bacterial cellulose membranes. (a) RH-H₂O; (b) RHA-H₂O; (c) RH-NaOH; (d) RHA-NaOH; (e) bacterial cellulose membrane

Table 2. Water retention capacity of BC membrane

Membrane	Dry mass / g	Wet mass / g	Water absorption percentage / %
BC-RHAL (H ₂ O)	4.8887	5.8698	16.7
BC-RHAL (NaOH)	5.8824	6.1003	3.6

BC-RHAL: bacterial cellulose-rice husk ash leached. Source: Authors.

Table 3. Results of modulus of elasticity and maximum tension for pure and functionalized BC

Sample	Modulus of elasticity / MPa	Maximum tension / MPa
BC pure	5.8 ± 0.7	16.2 ± 1.6
BC-RHL (H ₂ O)	4.5 ± 1.7	10.1 ± 3.3
BC-RHAL (H ₂ O)	4.3 ± 2.1	10.9 ± 5.8
BC-RHL (NaOH)	6.7 ± 4.7	11.6 ± 5.6
BC-RHAL (NaOH)	5.4 ± 3.0	10.8 ± 0.9

BC-RHL: bacterial cellulose-rice husk leached; BC-RHAL: bacterial cellulose-rice husk ash leached. Source: Authors.

bond between fibers, thus reducing the ability of the BC to react elastically to an applied load.²⁹ Despite the reduction in mechanical strength of silicon-functionalized BC, the membranes can still be used as controlled release systems. Furthermore, functionalized BC tends to become more brittle or less durable with handling or exposure to external stresses in agricultural environments. Nevertheless, the membranes have sufficient mechanical strength to be used in soil without breaking.

The chemical composition of the four BC samples subjected to contact with various leachates was determined using energy dispersive X-ray spectroscopy (EDX) in conjunction with SEM.

Table 4 presents the percentages of silicon found in the functionalized BC membranes. The highest value was for the BC membranes immersed in the extracts resulting from RHA with NaOH, with 13.2% by mass of SiO₂.

Table 4. Percentage of silicon in functionalized BC membranes

Sample	Silicon / wt. %
BC-RHL (H ₂ O)	0.2
BC-RHAL (H ₂ O)	0.035
BC-RHL (NaOH)	0.02
BC-RHAL (NaOH)	13.2

BC-RHL: bacterial cellulose-rice husk leached; BC-RHAL: bacterial cellulose-rice husk ash leached. Source: Authors.

Silica release test

Figure 4 shows the evolution of the silica content released from the BC membranes that were functionalized by RH and RHA leachate in pure water. The results demonstrated that 58% of the silica adsorbed by the BC membrane from the RH-leaching solution was released in 24 h. It was also noted that 67% of the silica adsorbed by the BC membrane from the leached RHA solution was released within 24 h. The greater silica release by the BC membrane from the RHA leaching solution will be investigated further with additional studies.

Figure 5 shows the evolution of the silica content released from

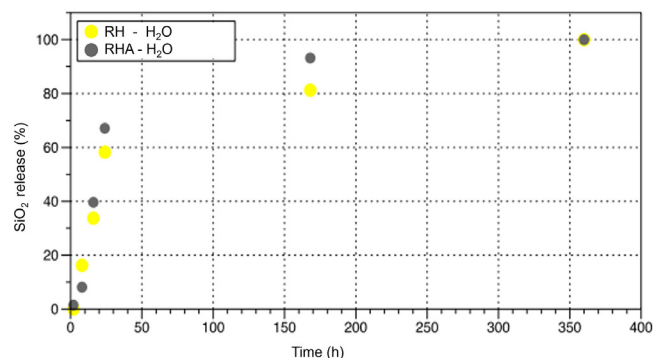


Figure 4. Controlled release of silica supported on BC functionalized with RH and RHA leached in pure water

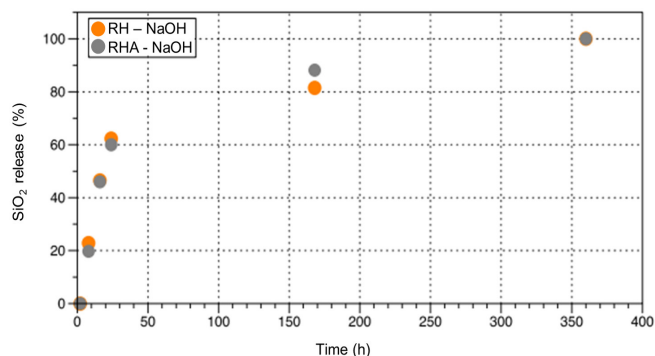


Figure 5. Controlled release of silica supported on BC functionalized with RH and RHA leached in NaOH

the BC membranes that were functionalized by RH and RHA leachate in NaOH solution.

The results demonstrated that 62% of the silica adsorbed by the BC membrane from the RH-leaching solution was released within 24 h. It was also noted that 60% of the silica adsorbed by the BC membrane from the leached RHA solution was released in 24 h.

As observed in Figures 4 and 5, 100% of the silica adsorbed by the BC membrane was released after 15 days. The shape of these curves represents an initial rapid release of silicon favoring an increase in nutrient uptake and water retention, as well as protecting stress signaling pathways. However, this benefit may not be sustained for a much longer period, depending on the amount of remaining silica released and the plant's need.

The water contained in the membrane improves the conduction and exchange of ions from the membrane to the soil and from the soil to the plants and the release of nutrients in a diffuse and controlled manner.⁹ Hydroxyl reactive group of the cellulose present in BC membranes are capable to interact with functionalizing agents. Consequently, if cellulose has not been modified, ions H⁺ can be exchanged with the ions Na⁺ of the saline solution. If the saline solution interacts with SiO₂, this capacity is modified. Dissolved silica contains groups that make nanocomposite membranes more hydrophilic, which provides greater ion exchange capacity. The IEC of the pure BC membranes presented values close to zero, which is recommended for applications as fertilizers.³⁰ The results indicated that the ion exchange capacity (Figure 6) of the BC membranes increased with the concentration of silica adsorbed by the membrane. The BC membrane containing silica from the NaOH extraction solution showed the highest IEC value of 0.1 eq g⁻¹.

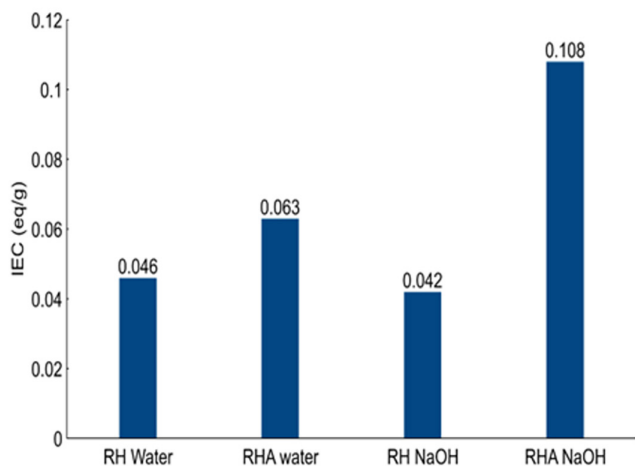


Figure 6. Ion exchange capacity of BC membranes containing silica from RH and RHA leaching

CONCLUSIONS

The results showed that for the extraction of silica from both RH and RHA, the NaOH solution showed promising results, with extraction of up to 75% of the silica.

Dissolved silica contains groups that make nanocomposite membranes more hydrophilic, as the fibrillar structure of BC was partially lost due to NaOH, the effect of silicon to make the membrane more hydrophilic did not perform as expected. However, the water contained in the membrane still improved the conduction and exchange of ions from the membrane. Therefore, it has become a suitable option for agriculture, especially for eroded soils. The mechanical characterization of the supported BCs revealed that the mechanical resistance of the BCs varied between 4.3 and 6.7 MPa, and it was not possible to confirm that there was a significant difference between the mechanical properties of the functionalized membranes, which can be used without handling problems in plantations. These materials can be used without problems of interest for agricultural crops.

The initial rapid rate of silicon release followed by a slow silicon release by BC occurred in a sustained manner that may favor the initial needs of plants, indicating the potential of the developed composite for agricultural applications.

ACKNOWLEDGMENTS

We gratefully acknowledge CAPES, FAPESC, CNPq for financial support and the Federal University of Santa Catarina.

REFERENCES

- Channab, B.-E.; El Idrissi, A.; Essamlali, Y.; Zahouily, M.; *J. Environ. Manage.* **2024**, *352*, 119928. [Crossref]
- Ashok, K. P. A.; Saeed, P. A.; Manholi, S.; Sujith, A.; *J. Cleaner Prod.* **2024**, *451*, 141827. [Crossref]
- Su, B.; Yang, M.; Gao, B.; Li, Z.; Zhao, X.; Zhang, S.; Cheng, D.; Shen, T.; Yao, Y.; Yang, Y.; *J. Cleaner Prod.* **2024**, *452*, 142145. [Crossref]
- Channab, B.-E.; El Idrissi, A.; Zahouily, M.; Essamlali, Y.; White, J. C.; *Int. J. Biol. Macromol.* **2023**, *238*, 124075. [Crossref]
- Srivani, G.; Kumar, G. S.; Janaguiraman, M.; Arthanari, P. M.; Malathi, P.; Priya, R. S.; Jagathjothi, N.; Yuvaraj, M.; Parasuraman, P.; *Silicon* **2024**, *16*, 5501. [Crossref]
- Chen, W.; Yao, X.; Cai, K.; Chen, J.; *Biol. Trace Elem. Res.* **2011**, *142*, 67. [Crossref]
- Tayade, R.; Ghimire, A.; Khan, W.; Lay, L.; Attipoe, J. Q.; Kim, Y.; *Biomolecules* **2022**, *12*, 1027. [Crossref]
- Coskun, D.; Britto, D. T.; Huynh, W. Q.; Kronzucker, H. J.; *Front. Plant Sci.* **2016**, *7*, 1072. [Crossref]
- Diaz-Ramirez, J.; Urbina, L.; Eceiza, A.; Retegi, A.; Gabilondo, N.; *Int. J. Biol. Macromol.* **2021**, *191*, 1212. [Crossref]
- Schwanke, A. J.; Maffi, G. M.; Sachse, A.; Radtke, C.; Bernardo-Gusmão, K.; Balzer, R.; *Mol. Catal.* **2022**, *529*, 112529. [Crossref]
- Solarte, A.; Choque, B.; Yagama, C. P.; Amaya, S. U.; *Structures* **2024**, *61*, 106111. [Crossref]
- Grotto, C. G. L.; Colares, C. J. G.; Lima, D. R.; Pereira, D. H.; do Vale, A. T.; *Biomass Bioenergy* **2020**, *142*, 105816. [Crossref]
- Fernandes, I. J.; Moraes, C. A. M.; Egea, J. R. J.; Sousa, V. C.; *Powder Technol.* **2024**, *436*, 119473. [Crossref]
- Camargo-Perez, R.; Moreno-Navarro, F.; Alvarez, A. E.; Walubita, L. F.; Fuentes, L.; *Constr. Build. Mater.* **2024**, *414*, 134832. [Crossref]
- Hermawan, R.; Cahyadi, Suryosatyo, A.; Tosuli, Y. T.; Dafiqurrohman, H.; *Case Studies in Thermal Engineering* **2024**, *56*, 104182. [Crossref]

16. Sudhir, S.; Soren, S.; Chowdhury, G. M.; Jaiswal, R. K.; Nirala, A.; Khan, M. A.; Alkahtani, M. Q.; Islam, S.; Algburi, S.; *Environ. Technol. Innovation* **2024**, *34*, 103597. [Crossref]
17. Kamruzzaman, M.; Shahriyar, M.; Bhuiyan, A. A.; Bhattacharjya, D. K.; Islam, M. K.; Alam, E.; *Energy Reports* **2024**, *11*, 3450. [Crossref]
18. Farid, S. A.; Zaheer, M. M.; *Mater. Today: Proc.* **2023**. [Crossref]
19. Shirgire, A.; Thenmozhi, S.; Jesuraj, V. P.; Shelar, A.; Chavhan, V. S.; Javanjal, V.; *Mater. Today: Proc.* **2024**, *103*, 594. [Crossref]
20. dos Santos, C. C.; Martins, P. V. F.; *Mix Sustentável* **2024**, *10*, 17. [Crossref]
21. Andi Grefa, D. D.; Guevara Sánchez, J. E.; Bravo Sánchez, L. R.; Pomares Alfonso, M. S.; Villanueva Tagle, M. E.; *Microchem. J.* **2023**, *195*, 109361. [Crossref]
22. Peralta, Y. M.; Molina, R.; Moreno, S.; *J. Environ. Chem. Eng.* **2024**, *12*, 112370. [Crossref]
23. Nzereogu, P. U.; Omah, A. D.; Ezema, F. I.; Iwuoha, E. I.; Nwanya, A. C.; *Hybrid Advances* **2023**, *4*, 100111. [Crossref]
24. Recouvreux, D. O. S.: *Desenvolvimento de Novos Biomateriais Baseados em Celulose Bacteriana para Aplicações Biomédicas e de Engenharia de Tecidos*; PhD Thesis, Universidade Federal de Santa Catarina, 2008. [Link] accessed in December 2024
25. Haq, I. U.; Akhtar, K.; Malik, A.; *J. Chem. Soc. Pak.* **2014**, *36*, 382. [Link] accessed in December 2024
26. Lin, C. W.; Liang, S. S.; Chen, S. W.; Lai, J. T.; *J. Power Sources* **2013**, *232*, 297. [Crossref]
27. Lateef, A.; Nazir, R.; Jamil, N.; Alam, S.; Shah, R.; Khan, M. N.; Saleem, M.; *Microporous Mesoporous Mater.* **2016**, *232*, 174. [Crossref]
28. Dikshit, P. K.; Kim, B. S.; *Int. J. Biol. Macromol.* **2020**, *153*, 902. [Crossref]
29. Sheykhazari, S.; Tabarsa, T.; Ashori, A.; Ghanbari, A.; *Int. J. Biol. Macromol.* **2016**, *93*, 672. [Crossref]
30. Songkhum, P.; Wuttikhun, T.; Chanlek, N.; Khemthong, P.; Laohasurayotin, K.; *Appl. Clay Sci.* **2018**, *152*, 311. [Crossref]