

Cellulosic materials as precursors of fouling-resistant membranes for salt removal

Materiales celulósicos como precursores de membranas con resistencia al ensuciamiento para la remoción de sales

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Abstract

[Objective] The objective was to verify the effectiveness of synthesized membranes derived from horsetail, nopal, moringa seed, tamarind seed, and from mixtures of these four species in the desalination–purification process of brackish water. **[Methodology]** Four plant species were selected to evaluate their efficiency in water treatment: Horsetail (*Equisetum giganteum*), Tamarind (*Tamarindus indica*), Moringa (*Moringa oleifera*), and Nopal (*Opuntia ficus-indica*). These species were physiochemically characterized in accordance with COVENIN standards for pH, moisture content, ash, fat, and conductivity. Brackish water sourced from the Santa Teresa well, Puerto Cumarebo, Falcón State, was also analyzed. Statistical analysis was performed using Minitab 17® software, and Tukey's comparison test was applied with a p-value ($p \geq 0.05$). **[Results]** Among the properties of greatest interest, the low moisture content observed in moringa (5.21%) and tamarind (9.27%) stands out. The plant material was processed to obtain silica (horsetail), tamarind flour, calcium carbonate (moringa), and nopal mucilage, giving rise to the vegetable membranes. Once the water was treated using the synthesized product, analyses of chlorides, calcium hardness, total alkalinity, phenolphthalein alkalinity, total solids, suspended solids, dissolved solids, conductivity, and pH were carried out. **[Conclusion]** The moringa membrane can be used as a purifier for brackish water, as it showed the best performance compared to horsetail, tamarind, and nopal membranes. Therefore, the use of moringa-based membranes is concluded and recommended.

Keywords: Chemical processes; membranes; desalination–purification; brackish water; cellulosic material.

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Resumen

[Objetivo] El objetivo fue comprobar la efectividad de las membranas sintetizadas partiendo de cola de caballo, nopal, semilla de moringa, semilla de tamarindo y de las mezclas de estas cuatro especies en el proceso de desalinización-purificación de aguas salobres. **[Metodología]** Se seleccionaron cuatro especies vegetales con el objetivo de evaluar la eficiencia de estas en el tratamiento del agua, entre ellas Cola de Caballo (*Equisetum giganteum*), Tamarindo (*Tamarindus indica*), Moringa (*Moringa oleífera*) y Nopal (*Opuntia ficus-indica*), las cuales fueron caracterizadas fisicoquímicamente siguiendo las normas COVENIN para pH, humedad, ceniza, grasa y conductividad. Y agua salobre procedente del pozo Santa Teresa Puerto Cumarebo, Estado Falcón. Se aplicó análisis estadístico con el software Minitab 17® se realizó comparación de Tuckey con p-valor ($p \geq 0,05$). **[Resultados]** Entre las propiedades de mayor interés resaltan la baja humedad presentada por la moringa 5,21 % y el tamarindo 9,27 %. Se procesó la materia vegetal para obtener el sílice (cola de caballo), harina de tamarindo, carbonato de calcio (moringa) y mucilago de nopal, dando origen a las membranas vegetales. Una vez procesada el agua mediante el producto sintetizado, se aplicaron los análisis de cloruros, dureza cálcica, alcalinidad total, alcalinidad a la fenolftaleína, sólidos totales, sólidos suspendidos, sólidos disueltos, conductividad y pH. **[Conclusión]** la membrana de moringa puede ser usada como purificante de aguas salobres ya que fue la que mejor comportamiento presentó frente a las de cola de caballo, tamarindo y nopal, por lo cual se concluye y recomienda la membrana a base de moringa.

Palabras clave: Procesos Químico; membranas, desalinización-purificación; agua salobre; material celulósico

Introduction

Nowadays, the issue of freshwater reserves is a matter of global concern, as it is well known that the percentage of this liquid is very limited in comparison with other types of water (Aqua, 2018). Therefore, it is important to emphasize that the most abundant source of this vital liquid on the planet continues to be salt water, which has generated great interest in its purification and desalination (Luchsinger et al., 2017). This can be achieved through industrial plants such as multi-stage flash distillation or multi-effect distillation, as well as membrane-based technologies such as reverse osmosis.

However, there are other alternatives, such as treatment using membranes of plant or animal origin. This is a natural technology used for the purification and desalination of water, which could replace chemical coagulants such as mineral salts of iron (Fe^{3+}) or aluminum (Al^{3+}). These chemical coagulants pose a problem due to the large amount of sludge generated, which becomes an environmental and, above all, an economic challenge (Romero I., 2018). Membranes of plant origin act as natural coagulants derived from extracts of seeds, leaves, bark or sap, roots, and fruits of trees or plants, are capable of neutralizing the electrostatic charges of colloids suspended in water, thereby allowing agglomeration until sediments are formed (Villabona et al., 2013).

For the desalination membrane, plant-derived silica will be used due to the high silica content present in plant species, as silica gels prepared with biosilica (plant matter) function as effective moisture adsorbents and, more specifically, generate a characteristic pore size suitable for the desalination of brackish water (Luchsinger et al., 2017). In addition to this, the membranes to be produced, besides containing a percentage of silica, possess properties such as polysaccharides, carbohydrates, proteins, and amino acids, which confer coagulating or flocculating capacity.

In this regard, four plants were randomly selected: horsetail (*Equisetum giganteum*), nopal (*Opuntia ficus-indica*), moringa seed (*Moringa oleifera*), and tamarind seed (*Tamarindus indica*). Firstly, horsetail (*E. giganteum*), belonging to the Equisetaceae family, is a non-toxic medicinal plant (at low concentrations) found in the Venezuelan Andean states. It is characterized by branches with a high silica content, a substance that, as previously mentioned, provides desalination properties. In contrast, nopal (*Opuntia ficus-indica*), from the Cactaceae family, originates from arid regions of Cuba, Egypt, Spain, India, Israel, Brazil, and Venezuela. Romero (I. Romero, 2018) states that it “is characterized by the production of a hydrocolloid known as mucilage, which forms molecular networks capable of retaining large amounts of water” (p. 2).

On the other hand, moringa seed (*Moringa oleifera*), from the Moringaceae family, is a non-toxic tropical plant (at low concentrations) distributed throughout India, Asia, sub-Saharan Africa, and Latin America (I. Romero, 2018). This seed provides coagulating power by capturing suspended particles in water, causing them to bind together and precipitate at the bottom. Finally, tamarind seed (*Tamarindus indica*), which belongs to the

legume family and the Caesalpinioideae subfamily, is a plant native to the dry savannahs of tropical Africa. Its seeds contain coagulating properties for turbidity removal. It is important to highlight that in Japan, the use of refined tamarind seed powder has been approved, specifically within the food industry as an additive, gelling agent, thickener, or stabilizer, and it exhibits film-forming properties (Crispin, 2019).

The scope of this experimental research was limited to evaluating the effectiveness of membranes synthesized from horsetail, nopal, moringa seed, tamarind seed, and mixtures of these four species in the desalination–purification process of brackish water. It is expected that the findings of this study will serve as a basis for future research aimed at determining the feasibility of using this product at an industrial scale in brackish water desalination–purification processes.

Methodology

Sample Collection

A non-probabilistic, intentional sampling method was employed (Palela & Martins, 2006), based on: (1) the availability of plant species, and (2) their physicochemical properties, particularly ash content and pH. In addition, brackish water samples were selected based on having an alkaline pH and a well-based origin.

Moringa seeds were collected from the long, woody pods of the moringa tree, while tamarind seeds were obtained from the fruit. Subsequently, cladodes were extracted from the nopal plant to obtain mucilage, and finally, horsetail branches were collected. All sampling procedures followed the criteria established by Venezuelan standard COVENIN 612-82 (1982), “Cereals, Legumes, Oilseeds and Derived Products — Sampling”.

The plant specimens were collected from different regions of Venezuela, including Santa Ana de Coro and Punto Fijo (Falcón State), Barquisimeto (Lara State), and Mérida (Mérida State). These areas were selected due to their proximity to the study site and the favorable climatic conditions that promote the abundance of these species.

Brackish water samples were collected from an underground well located in the community of Santa Teresa, Puerto Cumarebo, Falcón State. This well represents the only provisional water supply subsystem for the local population due to the scarcity of potable water. Given the proximity of the area to the sea, the water exhibits physicochemical characteristics that render it unsuitable for human consumption. Sample collection was conducted following the manual sampling procedure established in Venezuelan standard COVENIN 2709-02 (2002), “Natural, Industrial and Waste Waters — Guide for Sampling Techniques (1st revision)” (p. 4).

Sample Characterization

Physicochemical characterization of each plant species was performed according to established Venezuelan standards, including: COVENIN 1553-80 (1980), “Cereal and Legume Products — Determination of Moisture”; COVENIN 1315-79 (1979), “Foods — Determination of pH (Ionic Acidity)”; COVENIN 2964-92 (1992), “Method for Calibration of Conductivity Cells”, used to determine conductivity; COVENIN 1783-81 (1981), “Cereal and Legume Products — Determination of Ash Content”; and COVENIN 1785-81 (1981), “Cereal and Legume Products — Determination of Fat Content”.

Analysis of Water Samples (Well Water)

Analyses were performed on the (brackish water) samples in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA et al., 1989), including Method 2540 B: “Solids — Total Solids (St)” $St = \frac{P_2 - P_1 \times 10^6}{V_m}$ (Eq.1)
Where: P_1 is the initial weight of the sample; P_2 is the final weight of the sample; and V_m is the sample volume.

2540 C and D. “Solids. Total dissolved solids (TDS) and Total Suspended Solids (TSS)”. $Sd = \frac{P_2 - P_1 \times 10^6}{V_m}$ (Eq. 2)

Where: P_2 is the weight of the beaker containing the solid sample; P_1 is the weight of the empty beaker; and V_m is the sample volume.

$$Ss = \frac{P_2 - P_1 \times 10^6}{V_m} \quad (\text{Eq.3})$$

Where: P_2 represents the weight of the filter paper containing the solid sample, P_1 corresponds to the weight of the empty filter paper, and V_m denotes the volume of the sample.

$$4500\text{-SO}_4^{2-} \text{ “Sulphate. Turbidimetric method” } [SO_4^{2-}] = \frac{Abs[SO_4^{2-}]}{m} \quad (\text{Eq. 4})$$

Where: a spectrophotometer was used at a wavelength of **420 nm**. $Abs[SO_4^{2-}]$: It represents the absorbance of the sulphate ion concentration. **m**: corresponds to the sample.

$$4500\text{-Cl}^- \text{ “Chloride. Argentometric method” } Cl^- = \frac{(Vg - Vb) \times N(AgNO_3) \times 71000}{V_m} \quad (\text{Eq. 5})$$

Where: V_m is the volume of the sample; V_g is the volume of silver nitrate solution consumed during the titration of the sample; V_b is the volume consumed by the blank; and N represents the normality of the silver nitrate solution.

The **COVENIN Standard 1315-79** was applied for the determination of **pH (ionic acidity)** in natural, industrial, and wastewater samples. In addition, the **Standard Methods for the Examination of Water**, Method **3500**, entitled “*Total and Calcium Hardness Analysis by EDTA Titration*”, was employed.

$$DCa = \frac{(A - B) \times 50\,000}{\text{sample volume (mL)}} \quad (\text{Eq. 6})$$

Where: A: is the volume (mL) of EDTA consumed during the titration of the sample using murexide as the indicator; B: is the volume (mL) of EDTA consumed during the titration of the blank; and C: represents the concentration of the EDTA solution.

Verification of the membranes

The plant-based membranes were evaluated to ensure compliance with water filtration requirements in the presence of heavy metals and salts from brackish water, in accordance with COVENIN Standard 2409-86 (1986), entitled “Water. Membrane filtration method for microbiological analysis”.

Preparation of plant-based membranes

The preparation of the plant-based membranes was carried out following a methodology modified from Luchsinger, Salas, Rodríguez, and Lujano (2017). For this purpose, the raw material *Equisetum giganteum* (horsetail) was suitably conditioned.

Washing of the raw material

The carbonized sample was washed with distilled water, as the target compound, silica (SiO_2), is insoluble in water. Finally, the solid carbonized material was placed in an oven at 100 °C for one hour to obtain a dry carbonized product.

Determination of moisture and SiO_2 content in the carbonized material

Moisture determination was carried out in accordance with COVENIN Standard 1553-80, entitled “Cereal and legume products. Determination of moisture content”. Likewise, the silica content in the carbonized horsetail material was determined using the gravimetric analysis method based on insolubility.

The carbonized material was treated in a basic medium (NaOH) as a sodium source, with the aim of obtaining sodium silicate (Na_2SiO_3). Thus, the reaction process between silica and aqueous sodium hydroxide (NaOH) was conducted in an autoclave under high pressure and temperature, without calcination, and is represented by the following reaction:



Synthesis of silica xerogel (membrane)

The synthesis of sodium silicate (Na_2SiO_3) as a precursor for silica gels was carried out following the procedure proposed by Foletto et al. (2006), based on a NaOH/ SiO_2 molar ratio of 2 M. Sodium hydroxide (NaOH) with a purity greater than 99% was used. Accordingly, once the usable silica content in the carbonized material was known, the amount of water required to immerse the carbonized sample was determined.

Hydrogel formation

To obtain the hydrogel, the procedure described by Luchsinger et al. (2017) was followed, in which an acid hydrolysis process was carried out to neutralize the sodium silicate using hydrochloric acid (HCl). The mixture was then stirred for one minute and allowed to gel, resulting in hydrogel formation at a total concentration of 7% (m/v).

Xerogel formation

To achieve the xerogel condition, the largest possible amount of solvent was removed from the previously formed hydrogel. For this purpose, absolute alcohol was used, resulting in the formation of an alcogel, which was subsequently dried in an oven at 25 °C for one hour. Finally, the sample was placed in a desiccator for 72 hours, where the xerogel was obtained.

Membrane derived from nopal (*Opuntia focus-indica*)

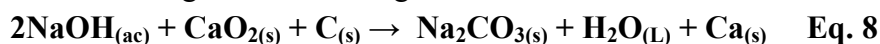
A modified methodology proposed by Villabona et al. (2013) was followed. The mucilage extraction process from nopal (*Opuntia focus-indica*) was carried out as follows: 1200 g of nopal cladodes were collected, washed, and peeled to remove the outer layer (cuticle). The material was then dried for 24 continuous hours at a temperature of 80 ± 1 °C.

Subsequently, the particle size of the dried material was reduced, yielding yellow-colored powder. The powder was sieved using a No. 80 sieve to obtain particles with a diameter of less than 0.5 mm, to favor pigment extraction. This fine powder was subjected to a pigment extraction process using 96% ethanol as the solvent. The powder acquired an ivory color and was then placed in a desiccator at ambient temperature (approximately 30 °C). Next, membrane formation was carried out by adjusting the pH with 1 N NaOH, followed by stirring at ambient temperature for 30 minutes, and subsequently neutralizing with 1 N HCl to a final pH of 7.37.

Membrane derived from moringa seed (*Moringa oleifera*)

The kernel was ground in a food processor until a flour-like consistency was obtained. The resulting flour was sieved using a No. 60 sieve to standardize particle size. Membrane preparation was carried out following a modified version of the plant-based membrane preparation methodology proposed by Luchsinger et al. (2017), incorporating a pre-treatment step consisting of degreasing the carbonised material prior to washing, as described in the previous section.

The reaction process between calcium oxide and aqueous sodium hydroxide (NaOH) was conducted in an autoclave under high pressure and temperature, without calcination, according to the following reaction, to form sodium carbonate:



Membrane derived from tamarind seed (*Tamarindus indica*)

The tamarind seed was conditioned following the same procedure applied to moringa seed. Subsequently, it was degreased using 96% ethanol, stirred for 30 minutes, and allowed to stand for 1 hour. The supernatant was discarded, and the sediment was placed on a watch glass and dried at ambient temperature for 2 hours.

Statistical analysis

Descriptive statistics were performed, presenting the mean values of the samples and their standard deviations. The membranes were subjected to Tukey's multiple comparison test, with significant differences indicated by letters between columns, according to the p-value ($p \geq 0.05$).

Analysis and Results

Table 1 presents the results obtained from the physicochemical characterisation of horsetail (*Equisetum giganteum*), nopal (*Opuntia ficus-indica*), moringa seed (*Moringa oleifera*), and tamarind seed (*Tamarindus indica*), with the aim of standardising each plant species and verifying, through detailed analysis, compliance with the specifications required for each plant material.

In this regard, the pH values for horsetail, nopal, moringa seed, and tamarind seed were 6.61, 5.06, 6.24, and 5.95, respectively, indicating that the samples exhibited a slightly acidic pH, due to the presence and activity of hydrogen ions in the medium. It should be noted that, according to Zara et al. (2017), these values may vary depending on the cultivation soil, as it confers specific characteristics to each species.

Similarly, Romero (2019) reported a pH value of 6.0 for horsetail; González (2019) obtained pH values ranging between 4.5 and 5.7 for nopal; Melón (2017) reported a pH of 5.44 for moringa; and Gurdián and Coto (2011) recorded a pH of 5.58 for tamarind, while Geethalaxmi et al. (2025) reported pH values of up to 6.10, depending on working conditions. However, when comparing the values obtained in this study with those reported in the literature, they were considered acceptable, as they fell within the reported ranges, thereby establishing the working pH ranges.

Later, the moisture content results for each plant were 74.75%, 77.49%, 5.21%, and 9.37%, respectively. In this context, Peláez and Pereda (2018) reported a moisture content of 7.32% for horsetail branches; Aguilar (2007) established a value of 64.10% for nopal; while Romero (2018) and Buenaño (2017) reported moisture contents of 8.61% and 8.07% for moringa and tamarind seeds, respectively. These references allowed confirmation of the values obtained in this study, demonstrating that moringa and tamarind exhibit lower water contents compared to the other plants. This characteristic delays chemical, enzymatic, and microbiological reactions, thereby allowing longer preservation periods.

Regarding ash content, which represents the mineralisation of organic material, the values obtained were 14.86% for horsetail, 1.99% for nopal, 58.04% for moringa, and

24.76% for tamarind. When compared with reference studies, Peláez and Pereda (2018) reported 5.88% for horsetail branches; Aguilar (2007) reported 1.80% for nopal; Romero (2018) reported 31.52% for moringa seed; and Crispín (2019) reported 4.10% ash content for tamarind seed. The values obtained in this study were considered to fall within the reference range. At this stage of characterisation, a significant variation was observed when comparing experimental values with those reported in the literature, suggesting the presence of minerals that may contribute to the water desalination process.

However, the fat content results obtained were 2.63%, 44.41%, and 8.57% for nopal, moringa seed, and tamarind seed, respectively. In the same way, previous studies demonstrated that Aguilar (2007) reported a fat content of 2% for nopal; Baldión and Steven (2019) reported values ranging from 32–40% for moringa seed; while Buenaño (2017) reported values between 4.5–16.2%, and Preetti et al. (2024) reported 6% for tamarind seed. In this sense, it can be stated that the values obtained were consistent with the characteristics of each plant species and were within the ranges reported in the literature. The lipid content presented in the studied materials might therefore favour the membrane formation process.

Finally, electrical conductivity results were obtained, with values of 11,500 $\mu\text{S}/\text{cm}$ for horsetail, 103,500 $\mu\text{S}/\text{cm}$ for nopal, 53,000 $\mu\text{S}/\text{cm}$ for moringa seed, and 2,575 $\mu\text{S}/\text{cm}$ for tamarind seed. In this regard, González (2019) explains that differences in the conductive capacity of a medium may depend on various factors, such as the type of soil from which the plant was obtained, which affects the mineral content transferred to the water.

Given that tamarind seed exhibited the lowest conductivity, it can be inferred that the ions present in brackish water may show lower conduction or retention through the membrane. Consequently, higher values of this property would favour the intended purpose, namely water desalination.

Tabla 1.

Physicochemical properties of the plant species

Parameters	Horsetail	Nopal	Moringa Seed	Tamarind Seed
pH	6,61 $\pm$ 0,01	5,06 $\pm$ 5 $\times 10^{-3}$	5,95 $\pm$ 0,08	6,24 $\pm$ 0,08
Moisture (%)	74,75 $\pm$ 0,06	77,49 $\pm$ 6,37	5,21 $\pm$ 0,21	9,37 $\pm$ 0,27
Ash (%)	14,86 $\pm$ 1,93	1,99 $\pm$ 0,84	58,04 $\pm$ 7,01	24,76 $\pm$ 0,88
Fat (%)	NP	2,63 $\pm$ 0,84	44,4 $\pm$ 0,18	8,57 $\pm$ 0,40
Conductivity ($\mu\text{S}/\text{cm}$)	11500 $\pm$ 500	103500 $\pm$ 500	53000 $\pm$ 5000	25750 $\pm$ 4150

Note: Derived from the present research. Values are expressed as the mean of $n = 2$ and their standard deviation. (NP): Not present.

Table 2 presents the results related to the quality of the final water, corresponding to the treatment of brackish water after filtration through the synthesised membranes, thereby demonstrating the effectiveness and performance of the different plant species as desalination–purification agents.

Statistically, groups were established according to the analysed parameters, comparing the membranes with the modified brackish water. Letters from a to f were used

to indicate statistical significance between treatments. Thus, through the exploratory assay conducted and its corresponding detailed analysis, it was demonstrated that:

The determination of chlorides (Cl^-) present in the samples provided an overall view of the desalination capacity of the synthesised membranes, since, according to previous studies, the Cl^- ion is one of the main contributors to the brackish character of water, proportionally affecting other properties such as electrical conductivity and pH, among others. In this regard, moringa and horsetail membranes proved to be effective in the removal of Cl^- ions present in the initial sample (709 ppm), yielding final concentrations of 354.5 ppm and 531.75 ppm, respectively.

Regarding calcium hardness and total alkalinity, expressed in units of ppm as CaCO_3 , the results demonstrated that treatment with the different membranes led to an average increase of approximately 286.4% in the hardness of the initial water (184 ppm), while simultaneously reducing total alkalinity by an average of 48.20% (134 ppm).

In the same way, it was observed that total solids decreased when using moringa, horsetail, and the mixed membranes, with reductions of 17,000, 11,000, and 9,000 ppm, respectively, compared to the initial value 33,000 ppm. However, in the case of tamarind and nopal, the opposite behaviour was observed; that is, total solids increased, rising from 33,000 ppm to 42,000 ppm and 36,000 ppm, respectively. This represents increases of 9,000 ppm and 3,000 ppm, which may be attributed to the carbohydrate (glucose) content of both nopal and tamarind, which confers viscosity to the water (Aguilar, 2007; Gurdíán & Coto, 2011).

Consequently, when analysing the results obtained for total dissolved solids (ppm), a decrease was observed with respect to the initial test, demonstrating greater effectiveness for moringa, horsetail, nopal, and the mixed membrane, with removals of 12,088.8889; 11,255.55; 8,666.6612; and 7,422.2223 ppm, respectively. In contrast, tamarind increased the dissolved solids by 18,333.3334 ppm. Suspended solids decreased mainly when using the mixed membrane (333.33 ppm), nopal (1,577.77 ppm), and moringa (4,911.11 ppm). Conversely, horsetail and tamarind exhibited a negative effect, increasing the initial value of 19,988.88 ppm to 23,666.66 ppm and 20,244.44 ppm, respectively, corresponding to increases of 3,677.78 ppm and 255.56 ppm.

pH was the parameter that showed the least variation during characterisation, with an average value of 8.245 for horsetail, moringa, nopal, and the mixed membrane, compared with the initial value of 8.295. However, tamarind was the only membrane that exerted a noticeable influence, reducing the pH to 7.845. This behaviour may be attributed to the fact that tamarind seed did not undergo the pressure and temperature treatment, which can affect seed properties related to pH (Geethalaxmi et al., 2025). In contrast, moringa seed and horsetail underwent a direct process involving hydrogen ion adjustment, due to their acidic nature (pH 6.24).

Regarding colour and turbidity, these analyses are considered essential parameters for determining the quality of the treated water. Colour, measured in Platinum–Cobalt units (Pt/Co), exhibited values ranging from 2.3157 to 194.2105, with the lowest value obtained using the moringa membrane. When compared with the initial value (40.5263), moringa was the only membrane that reduced the colour parameter. For turbidity, expressed in NTU (Nephelometric Turbidity Units) as a function of the mass of the applied preparation, the values obtained were: horsetail (58.2758), tamarind (159.6551), moringa (4.1379), nopal

(123.7931), and the mixed membrane (73.1034). The greatest removal efficiency was observed with the moringa seed membrane, reducing turbidity by 20.6956 NTU relative to the initial value, which corresponds to a removal efficiency of 83.35%. In comparison, Acevedo (2019) reported a 40% removal, achieving a final value of 2.73 NTU, in compliance with water quality standards.

It can be inferred that the moringa-based membrane exhibited the best removal performance, as it presented lower values across the evaluated parameters when compared with the modified initial water.

Table 2.

Physicochemical properties of well water and post-filtration water using plant-based membranes of horsetail (*E. giganteum*), tamarind seed (*T. indica*), moringa seed (*M. oleifera*), nopal (*O. ficus-indica*), and their mixture (*E. giganteum*, *T. indica*, *M. oleifera*, and *O. ficus-indica*).

Parameters	Well Water (initial) [c]	Post-membrane treatment				
		Horsetail [d]	Tamarind Seed [b]	Moringa Seed [e]	Nopal [a]	Mixture [c]
Cl ⁻ (ppm)	709±14,18d, c	531,75±7,09d	900,43±7,09b	354,5±14,18e	2226,26±0a	723,18±0c
D Ca (ppm CaCO ₃)	184±2d,e	438±2c	472±0b	278±0d	972±0a	472±0b
At (ppm CaCO ₃)	134±0d,a	68±0c	59±1c	47±1d	88±4b	61±1c
Phenolphthalein alkalinity	NP	NP	NP	NP	NP	NP
ST (ppm)	33000±1000 a,b	22000±0c	42000±0a	16000±0d	36000±2000b	24000±0c
SD (ppm)	13011,1112c,a	1755,5556 b	18333,3334a	922,2223 b	5588,8889 a	4344,45 b
SS (ppm)	19988,88±55,56b, a, b	20244,44±88,89 a, b	23666,66±1800 a	15077,77±211,11 c	18411,11±233,33 b,c	19655,55±455,56 a, b
Conductivity (μS/cm)	1663±6 d, d	1919±0,5 e	1610±0,5 a	1682±0,5 f	4850±0,5 c	1893±1,5 b
pH	8,295±0,2 d, b	8,35±0,04 b	7,845±5x10 ⁻³ e	8,515±5x10 ⁻³ a	8,105±5x10 ⁻³ c	8,01±0,03 d
Color (Pt/Co)	40,5263 d, e	112,1051c	96,8421d	2,3157 f	194,2105 a	114,2105 b
Turbidity (UNT)	24,8275d, e	58,2758d	159,6551a	4,1379f	123,7931b	73,1034c

Note: Derived from the research. Values are presented as the mean of n = 2 and their standard deviation. Cl⁻: Chlorides; D Ca: Calcium hardness; TA: Total alkalinity; TS: Total solids; DS: Dissolved solids; SS: Suspended solids. (NP) Not present. Identical letters within rows indicate no statistically significant differences among the species.

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Conclusions

- To achieve the objective, four (4) plant species (*E. giganteum*, *O. ficus-indica*, *M. oleifera* and *T. indica*) were selected due to their specific properties for use as membranes. Preliminary analyses were conducted, including pH, which ranged from 5.06 to 6.61; fat content from 2.63 to 44.4%; ash content from 1.99 to 58.04%; moisture from 5.21 to 77.49%; and conductivity from 11,500 to 103,500 $\mu\text{S}/\text{cm}$. These parameters were evaluated according to quality standards and are of great importance for the water desalination–purification process.
- The physicochemical conditions of the brackish water from the Santa Teresa well, Puerto Cumarebo, Falcón State, were initially determined. The most relevant characteristics were: pH 8.40; conductivity 1,663 $\mu\text{S}/\text{cm}$; chlorides 709 ppm; total solids (TS) 33,000 ppm; dissolved solids (DS) 13,011.11 ppm; suspended solids (SS) 19,988.89 ppm; colour 40.53 Pt–Co units; and turbidity 24.83 NTU.
- It was demonstrated that membranes of plant origin are efficient for the desalination–purification of brackish water, yielding acceptable results when compared with the initial conditions, such as: pH values from 7.85 to 8.35; conductivity from 1,610 to 4,850 $\mu\text{S}/\text{cm}$; chlorides from 354.5 to 2,226.26 ppm; TS from 16,000 to 42,000 ppm; DS from 922.22 to 18,333.33 ppm; SS from 15,077.78 to 23,666.67 ppm; colour from <2.32 to 194.21 Pt–Co units; and turbidity from 4.14 to 123.79 NTU. Among the evaluated materials, the moringa membrane showed the highest efficiency in the desalination and purification of brackish water.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contribution Statement

All authors declare that the final version of this article was read and approved.

CRedit Author Roles:

M.R.M.A.: Conceptualisation, Methodology, Software, Supervision, Review, Original Draft Writing.

G.S.D.J.: Investigation, Resources, Data Curation, Formal Analysis; Writing, Visualisation.

P.L.J.J.: Validation, Investigation, Resources, Data Curation, Formal Analysis; Writing – Review and Original Draft Writing.

A.D.O. de J.: Review and Translation.

The total percentage contribution to this article was as follows: M.R.M.A. 30%; G.S.D.J. 30%; P.L.J.J. 30%; A.D.O. de J. 10%.

Data Availability Statement

The corresponding author, MRMA, will provide the data supporting the findings of this study upon reasonable request.

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