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Study of a new biocoagulant/bioflocculant mixture based on *Boscia senegalensis* seeds powder and *Aloe vera* leaves extract for the treatment of raw water intended for human consumption in rural areas of Sub-Saharan Africa

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Introduction: The research of natural and sustainable solutions to improve rural water quality in developing countries of Sub-Saharan Africa represents a major challenge. It is in this context that the aim of this study was to evaluate the efficacy of a biocoagulant/bioflocculant mixture based on *Boscia senegalensis* seeds powder and *Aloe vera* leaves extract for treating water intended for human consumption in rural areas.

Methods: To do this, 100 g of *Boscia senegalensis* seeds powder and 50 g of *Aloe vera* leaves extract were prepared separately as aqueous solutions in 1 L of distilled water, then applied, respectively, as biocoagulant for Boscia and bioflocculant for Aloe to raw water samples in jar tests. The quality of the treated water was evaluated, and compared with WHO standards of acceptability.

Results and discussion: Experimental results showed that the *Boscia senegalensis* biocoagulant (at 7 mL/L) initially reduced turbidity by 85% after 2 h of decantation. When combined with Aloe bioflocculant (at 0.4 mL/L), a 99% reduction was obtained after just 15 min of decantation. Quality control of the water treated with this biocoagulant/bioflocculant mixture showed perfect compliance of physicochemical parameters with WHO standards, and almost total elimination of pathogenic microorganisms. These results demonstrate the effectiveness of this new Boscia/Aloe mixture in the rapid potabilization of raw water intended for human consumption. However, prolonged storage of water treated with the Boscia/Aloe mixture at room temperature may lead to further bacterial proliferation due to the remaining organic matter. To avoid this problem, additional disinfection methods such as boiling, SODIS (Solar Disinfection) method or sand filtration are recommended for prolonged storage of treated water. Ultimately, the adoption of this environmentally-friendly biotechnology could not only improve public health, but also empower local communities in Sub-Saharan Africa by providing them with a local and effective methodology for tackling the growing challenges associated with access to drinking water.

KEYWORDS

Boscia senegalensis, *Aloe vera*, water, biocoagulant, bioflocculant

1 Introduction

In many low income countries in the world, access to drinking water remains a major challenge, affecting people's health and well-being (Bazaanah and Mothapo, 2023). Despite the progress made in water supply, millions of people continue to suffer from a lack of safe water resources. This precarious situation exposes the most vulnerable communities to a wide range of water-borne diseases, compromising their ability to live healthy and productive lives (Ashrafuzzaman et al., 2023; Bhaduri et al., 2021; Zerbo et al., 2020). In this context, the availability and quality of water for human consumption remain crucial issues. In rural areas of Sub-Saharan Africa, many available water sources are unhealthy (highly turbid and contaminated water), making their consumption a health hazard (Gwimbi et al., 2019). Unfortunately, water treatment infrastructures in these areas are often limited, inefficient or even non-existent, leaving populations exposed to serious health risks (Iribarnegaray et al., 2021; Tucker et al., 2022).

Faced with this reality, some communities are turning to traditional potabilization solutions based on indigenous plant extracts, with the aim of improving water quality in an affordable and sustainable way (Adeeyo et al., 2021; Breuer and Spring, 2020; Villena-Martínez et al., 2023). These plants, often locally available and sustainably cultivated, have been used in some cultures for generations to remove impurities from water.

However, despite their long-standing use and importance in many communities, this traditional approach to water treatment still requires more scientific research (Crini, 2005). The precise purification mechanisms, optimal conditions of use and actual efficacy of many plant coagulants are often unclear, limiting their widespread adoption and integration into rural water management policies (Lichtfouse et al., 2019; Varsani et al., 2022).

The present study aims to explore the potential of a new biocoagulant/bioflocculant mixture based on *Boscia senegalensis* seeds and *Aloe vera* leaves in the treatment of water destined for human consumption in rural areas. The choice of these two plant extracts is based on their proven potential for purifying raw water in certain rural areas of Burkina Faso. *Boscia senegalensis*, also named hanza, is a shrub widespread in the east of the country, whose seeds are reputed to be effective in clarifying unsafe water (Rivera-Vega et al., 2015).

Aloe vera is also a plant found in Burkina Faso and widely known for its medicinal and cosmetic uses. Although it is not commonly used in water treatment, some studies have explored its potential and presented intrinsic characteristics favorable to its use in this field. Its mucilaginous character suggests that it could be an excellent bioflocculant for the treatment of unsafe water in mixture with *Boscia senegalensis* seeds. The combined use of these two extracts is still largely unexplored, paving the way for innovative research in the field of water treatment. By combining the biocoagulant properties of *Boscia senegalensis* seeds and the bioflocculant properties of *Aloe vera* sap, an effective, economical and environmentally-friendly treatment is envisaged.

This study is part of a sustainable development approach, aimed at offering an affordable, ecologically viable solution adapted to the realities of poor countries in terms of access to drinking water. By exploring the potential of this innovative mixture, the study aims to help improve access to quality drinking water and promote public health in these disadvantaged regions.

2 Materials and methods

2.1 Sampling

Boscia senegalensis seeds and *Aloe vera* leaves were collected with the technical support of the National Center of Forest Seeds of Burkina Faso (NCFS) in March 2022. The mature Boscia seeds were collected in the village of Kantchari in the Eastern region, while the *Aloe vera* leaves were collected in a NCFS tree nursery in the city of Ouagadougou. Groundwater samples were collected from a traditional well in the village of Nasso (11°12′49″N, 4°26′12″W), while surface water samples were collected from the Loumbila dam (12°29′N, 01°24′W). All water samples taken at each site were collected in plastic canisters, transported to the laboratory, then stored in a refrigerator at 4°C in accordance with the French standard NF EN ISO 5667-3 (2004) described by Konkobo et al. (2021) (Figure 1).

2.2 Methodology

2.2.1 Preparation of extracts in solution

Boscia senegalensis seeds are dried before being ground into a fine powder. Drying is a crucial step in reducing the moisture content of the seeds, facilitating their transformation into powder and preserving the stability of the active phytochemical compounds. Once the powder was obtained, 100 g were added to 1 L of distilled water, and the mixture was subjected to magnetic stirring for 2 h to extract as many active molecules as possible. The homogenized solution was then filtered, and the filtrate obtained constituted Boscia's biocoagulant stock solution.

For the preparation of the Aloe bioflocculant solution, 50 g of fresh leaves, properly washed, were crushed immediately after harvest. This crushing released the pulp and active compounds from the leaves, which was then homogenized in 1 L of distilled water using magnetic stirring. This step is crucial to dissolve and extract the sap, a substance rich in mucilage and polysaccharides. After homogenization for 2 h, the mixture was filtered to separate the sap from the rest of the plant

FIGURE 1
Boscia senegalensis seed **(A)**; *Aloe vera* leaves **(B)**; Loumbila dam sampling site **(C)**; Nasso well sampling site **(D)**.

material. The filtrate obtained constituted Aloe bioflocculant stock solution.

2.2.2 Evaluation of the purification capacity of Boscia and *Aloe vera* extracts

The purification capacity of Boscia and Aloe extracts was evaluated using jar tests on collected groundwater and surface water samples. The jar test, also known as the coagulation/flocculation decantation test, is a laboratory procedure used to simulate a small-scale water treatment process in order to determine the optimum concentration of coagulants or flocculants, as well as the minimum decantation time required to remove suspended particles from the water. In this study, this was carried out using a *Velp Scientifica* six-station flocculator, and enabled us to assess the purification capacity of *Boscia senegalensis* extracts as a biocoagulant and *Aloe vera* extracts as a bioflocculant.

During jars test, increasingly larger volumes of *Boscia senegalensis* biocoagulant extract were first introduced into flocculator beakers, each containing 1 L of raw water sample to be treated. The mixture was then rapidly agitated by the flocculator at 150 rpm for 5 min. This rapid agitation phase disperses the biocoagulant extract evenly in the water sample. In a second phase larger volumes of *Aloe vera* bioflocculant extract were added; agitation was then slowed down to 45 rpm for 10 min. This slow phase allows destabilized particles to agglomerate to form larger flocs, which are likely to settle much more rapidly due to their higher mass. The turbidity of the water above the flocs thus begins to fall considerably, and the optimum concentration of biocoagulant or bioflocculant is determined according to which beaker has achieved the lowest turbidity. The different treatments were carried out in triplicate for each concentration tested.

2.2.3 Quality control of water treated by the Boscia/Aloe mixture

2.2.3.1 Physicochemical parameters

The physicochemical parameters measured encompassed key factors related to health impact and the acceptability of drinking water. These included turbidity, pH, total hardness, conductivity, complete alkalimetric acidity (CAT), calcium and magnesium hardness (Ca^{2+}, Mg^{2+}), as well as the presence of certain minerals such as sodium, potassium, sulfates and chlorides.

Turbidity was determined using the nephelometric method with a WTW Turb 550 IR turbidimeter following the French standard NF ISO 7027 (2000), with results expressed in nephelometric turbidity units (NTU).

pH was measured using a pH meter (330i WTW) equipped with a combined electrode in accordance with method NF 10523 (1994).

Conductivity and temperature were measured with a conductivity meter coupled with a WTW thermometer. Results were reported in degrees Celsius (°C) for temperature and microsiemens per cm (μS/cm) for conductivity.

Complete alkalimetric acidity (CAT), was determined by titration, where 100 mL of water sample was titrated with 0.1 N HCl in the presence of phenolphthalein as an indicator for AT, and methyl orange for CAT, following French standards NF T 9963: 1996. They were expressed in mg/L.

Calcium, magnesium, and total hardness concentrations were determined by titrimetric method following French standards NF T 90-003: 1984 for total hardness and NF T 90-016: 1984 for calcium and magnesium.

Sodium and potassium ions were measured using a flame photometer. This involved introducing a small quantity of the water sample into a beaker, in which the apparatus probe was inserted. After a short period, the ions' content was revealed in mg/L. It's noteworthy that prior to any ion content measurement, the apparatus underwent calibration.

2.2.3.2 Microbiological parameters

Samples of water treated with the Boscia/Aloe mixture must be free of pathogens. For this reason, particular emphasis was placed on the microbiological quality of these treated waters. In accordance with current regulations, the main indicator organisms for faecal contamination were selected for this study. These include *Escherichia coli*, total coliforms, and streptococci. The determination of these organisms was carried out using the membrane filtration method (of 100 mL of water to be analyzed) and inoculation onto specific culture media onto specific culture media as per the French standard NF EN ISO 9308-1 (2014). Chromocult Coliform Agar ES medium was used for detecting total coliforms and *Escherichia coli*, with incubation at 37°C. Streptococci were identified using Enterrococus agar medium at 44°C.

2.3 Statistical analysis

All measurement experiments were performed in triplicate and the results were expressed as mean ± standard deviation (SD) of the mean. Graphs and tables were generated using GraphPad Prism (version 8.4.3) and Microsoft Excel (version 2016). The data were analyzed using analysis of variance (ANOVA), and significant differences between means were determined with Tukey's test ($p < 0.05$) using XLSTAT software (version 2016). Principal component analysis and hierarchical clustering were conducted using R software, version 4.0.2 (2020).

3 Results and discussion

3.1 Results

3.1.1 Influence of biocoagulant concentration on turbidity abatement

Coagulation-flocculation tests carried out on raw water samples showed a significant reduction in turbidity as a function of Boscia biocoagulant concentration after 1 h of decantation (Figure 2). Thus, the application of increasingly higher concentrations of Boscia biocoagulant (1 to 11 mL/L) reduced the turbidity of the surface water sample from 522.1 NTU to 76.4 NTU (for an optimal concentration of 7 mL/L); and in the groundwater sample from 172.5 to 24.2 NTU (after application of 8 mL/L). These reductions both correspond to an 85% reduction in turbidity, proving the capacity of *Boscia senegalensis* seeds to clarify raw water.

3.1.2 Influence of decanting time on the efficacy of Boscia biocoagulant

The results shown in Figure 3 demonstrate that the reduction in turbidity during treatment with Boscia is also influenced by the decanting time. A significant and progressive reduction in turbidity can be observed after the first 15 minutes of decanting, up to 2 h of time for optimal biocagulant concentrations of 7 mL/L and 8 mL/L, respectively, for surface and groundwater samples. Thus, after 2 h of decantation, the surface water sample went from 522.1 NTU to 4.4 NTU, and the groundwater sample from 172.2 to 4.7 NTU. It should be noted that these new turbidity values comply with the WHO recommended standard of 5 NTU maximum.

3.1.3 Optimizing treatment with the Boscia/Aloe mixture

Monitoring the turbidity of water samples through coagulation-flocculation tests with optimum concentrations of Boscia as biocoagulant, combined with increasing volumes of Aloe extract as bioflocculant, reduced the settling time required (Figure 4). In fact, the addition of volumes ranging from 0.1 to 1 mL/L of *Aloe vera* extract at the optimum concentrations of Boscia (7 mL/L and 8 mL/L) enabled turbidity in compliance with the standard to be obtained from 0.4 mL/L of water (4.5 NTU for the surface water sample and 4.4 NTU for the groundwater sample) in just 15 min of decantation. Optimization tests carried out by the Boscia/Aloe mixture considerably reduced the decanting time from 2 h to 15 min.

3.1.4 Effects of treatment on physicochemical and microbiological parameters

To further investigate the effectiveness of the Boscia/Aloe mixture, quality of water samples was changed significantly after treatment. Analysis of variance (at $p > 0.05$) shows that this mixture changed significantly water for almost all physicochemical parameters, with the exception of pH (Table 1).

Indeed, the addition of Boscia or Aloe extracts did not cause any significant variation in pH, whose value remained in the 7 to 8 range, which is perfectly in line with the standard recommended by the WHO. For other parameters such as conductivity, total hardness and concentrations of major cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+), there was a slight increase in their content in the treated water samples. In contrast to major cations, a decrease in the concentration of HCO_3^-, SO42-and

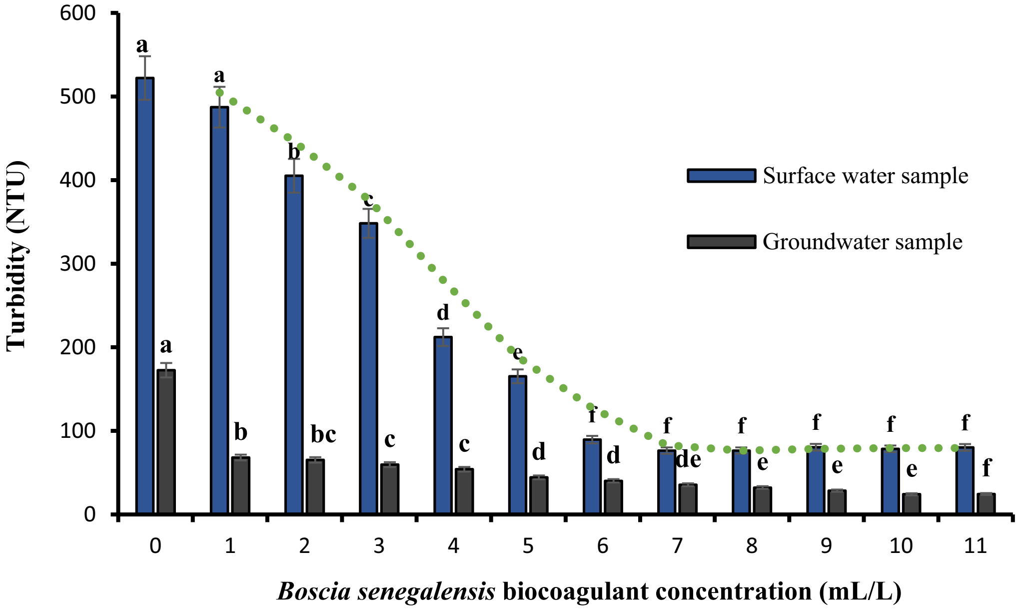

FIGURE 2
Variation of the turbidity of water samples as a function of *Boscia senegalensis* biocoagulant concentration. The letters "a, b, c, d, e, f" represent different levels of variation. Bars marked with the same letter show no statistically significant differences, while those marked with different letters indicate statistically distinct differences according to Tukey's HSD test at the 5% level.

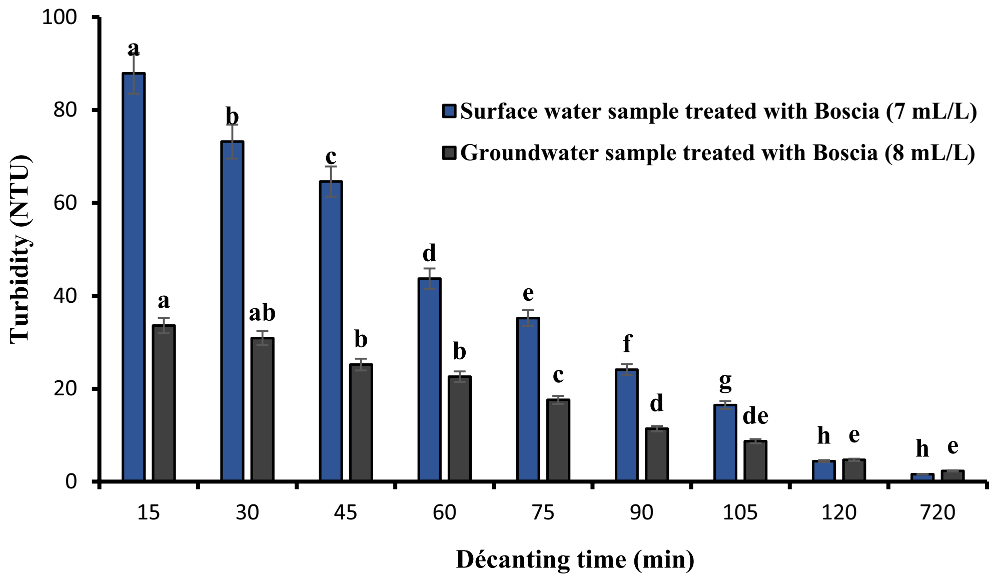

FIGURE 3
Variation of the turbidity of water samples treated with *Boscia senegalensis* as a function of decanting time. The letters "a, b, c, d, e, f, g, h" represent different levels of variation. Bars marked with the same letter show no statistically significant differences, while those marked with different letters indicate statistically distinct differences according to Tukey's HSD test at the 5% level.

Cl-anions was observed after application of the Boscia/Aloe mixture during treatment.

Microbiological analyses showed a considerable reduction in the various microbial indicators in each sample of water treated with the Boscia/Aloe mixture (Table 1). Total coliforms, *Escherichia coli* and enterococci, initially present in raw water samples, were reduced by almost 99% after treatment with the Boscia/Aloe mixture.

4 Discussion

The principal objective of this study was to evaluate the effectiveness of an innovative biocoagulant/bioflocculant mixture, based on *Boscia senegalensis* seeds and *Aloe vera* sap, in the treatment of water intended for human consumption. Experimental results showed that *Boscia senegalensis* seeds have the capacity to reduce the

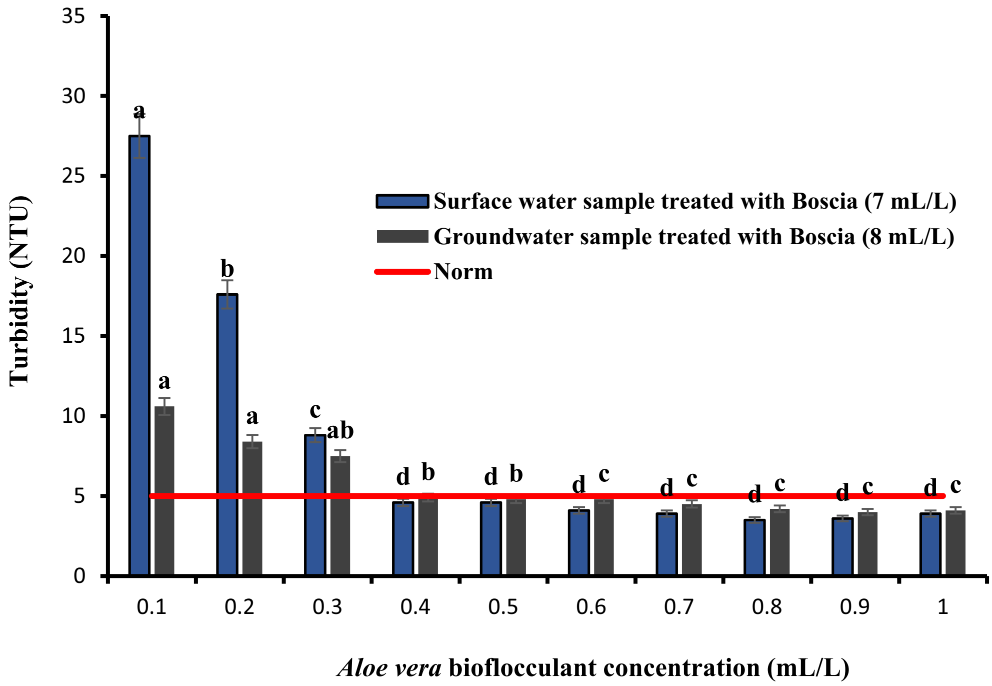

FIGURE 4
Variation of the turbidity of water samples as a function of the volume of *Aloe vera* extract applied with the optimum concentration of *Boscia senegalensis* biocogulant during treatment. The letters "a, b, c, d" represent different levels of variation. Bars marked with the same letter show no statistically significant differences, while those marked with different letters indicate statistically distinct differences.

TABLE 1 Physicochemical and microbiological parameters of water samples treated with the Boscia/Aloe mixture before and after treatment.

Physicochemical parameters				
Parameters	GW	SW	Treated GW	Treated SW
pH	6.76 ± 0.15^{bb}	7.20 ± 0.10^{aa}	6.63 ± 0.15^{bb}	6.86 ± 0.21^{abb}
Conductivity (µS/cm)	216.36 ± 5.18^{aa}	139.63 ± 6.33^{aa}	241.13 ± 13.16^{aa}	185.66 ± 14.52^{aa}
Total hardness (mg/L)	76.29 ± 1.31^{aa}	45.19 ± 6.60^{bb}	96.56 ± 7.00^{aa}	58.36 ± 1.91^{bb}
Ca^{2+} (mg/L)	44.36 ± 1.16^{aa}	29.93 ± 1.46^{cc}	52.63 ± 3.16^{bb}	36.26 ± 0.21^{cd}
Mg^{2+} (mg/L)	31.93 ± 2.44^{aa}	15.26 ± 2.15^{bc}	43.93 ± 1.72^{ab}	22.10 ± 0.70^{bc}
K^{+} (mg/L)	11.93 ± 0.96^{aa}	5.30 ± 0.66^{cc}	19.06 ± 0.61^{bb}	14.23 ± 0.60^{cc}
Na^{+} (mg/L)	20.23 ± 1.90^{aa}	15.66 ± 2.20^{bb}	27.86 ± 1.29^{abab}	20.90 ± 1.04^{cc}
HCO^{3-} (mg/L)	1.62 ± 0.10^{aa}	1.69 ± 0.45^{aa}	1.27 ± 0.13^{aa}	1.34 ± 0.20^{aa}
$SO4^{-2}$ (mg/L)	11.33 ± 0.5^{bb}	14.00 ± 1.00^{bb}	10.33 ± 0.58^{bb}	8.00 ± 2.00^{aa}
Cl^{-} (mg/L)	2.43 ± 0.57^{aa}	1.40 ± 0.20^{aa}	1.23 ± 0.38^{aa}	1.10 ± 0.36^{aa}
Microbiological parameters (UFC/100mL)				
Total coliforms	82.66 ± 5.03^{bb}	183.00 ± 28.62^{aa}	0.66 ± 1.15^{cc}	2.00 ± 2.00^{cc}
Escherichia coli	58.66 ± 4.62^{bb}	78.33 ± 5.86^{aa}	0.00	0.66 ± 1.15^{cc}
Enterococci	0.00	10.66 ± 1.53^{aa}	0.00	0.00

GW, groundwater; SW, surface water; Treated GW, raw groundwater; Treated SW, treated surface water. For each line, values with the same letter are not significantly different according to Tukey's HSD test at the 5% level.

turbidity of raw water through the aggregation and accelerated sedimentation of colloidal particles. This ability can be explained by the fact that Boscia seeds possess active molecules, notably cationic proteins capable of forming bridges between colloidal particles, thus facilitating their coagulation (Konkobo et al., 2024).

In this study, the mixture of *Boscia senegalensis* seeds and *Aloe vera* sap as biocoagulant and bioflocculant, respectively, demonstrated superior performance in terms of water clarification efficiency and speed. This improvement is probably due to the complementary action of the active components in Boscia seeds and Aloe, optimizing the coagulation and flocculation processes. According to some studies, the biocoagulant or bioflocculant capacity of plant extracts is strongly linked to the presence of functional groups such as polysaccharides, proteins, polyphenols, tannins, etc. (Bahrodin et al., 2021; Maćczak et al., 2020). Studies on the biochemical characterization of *Boscia senegalensis* seeds by authors such as Patchaiyappan and Devipriya (2021) have identified the presence of macromolecules (total carbohydrates, proteins, lipids) and secondary metabolites (polyphenols, flavonoids, tannins) whose synergistic action is responsible for the purifying capacity of these seeds. Other authors (Rivera-Vega et al., 2015; Saa et al., 2019) report in this regard that certain Boscia proteins, thanks to their charged functional groups (amine and carboxyl groups), can neutralize the charges of colloids, thus reducing electrostatic repulsion and facilitating their agglomeration. In this way, the secondary and tertiary structures of the proteins create multiple binding sites, enabling the proteins to form bridges between colloidal particles, thereby increasing the size and density of the flocs (Okoro et al., 2021; Teh et al., 2014). In addition, hydrophobic interactions between hydrophobic protein segments and hydrophobic colloids promote agglomeration (Rivière et al., 2020). Finally, proteins can form complexes with polyphenols and flavonoids, enhancing their ability to neutralize colloids and stabilize flocs, thus improving the overall efficiency of the water treatment process (Teixeira et al., 2024).

As for the chemical composition of *Aloe vera*, authors such as Delatorre-herrera et al. (2010) and Prisa and Spagnuolo (2022), report that this plant is a mucilaginous species, and that mucilages contain a significant quantity of carbohydrates present in polymeric (cellulose and starch) or monomeric form. These mucilages would therefore be responsible for the flocculent properties of Aloe sap during water treatment by coagulation/flocculation (Konkobo et al., 2023). Thus, the mixture of *Boscia senegalensis* seeds and *Aloe vera* sap in this study demonstrated an effective synergy in water purification. *Boscia senegalensis* seeds, rich in proteins and phenolic compounds, and *Aloe vera* mucilage, rich in carbohydrates (polysaccharides), act as excellent biocoagulants and bioflocculants respectively, helping to neutralize colloidal particle charges and facilitate their aggregation (Konkobo et al., 2023).

Many scientific studies report that, while the active substances of biocoagulants are generally carbohydrate, lipid or peptide compounds (Behloul and Zertal, 2020; Sillanpää et al., 2018), those of bioflocculants are mainly polysaccharides and mucilaginous compounds (Jenifer et al., 2021). However, most biocoagulants and bioflocculants based on plant extracts work mainly through an interparticle bridging adsorption and coagulation mechanism in which colloid destabilization takes place thanks to the active substances in each extract (Aziz et al., 2021).

Furthermore, quality control of water treated with the Boscia/Aloe mixture revealed an overall increase in conductivity. This increase is caused by the addition of minerals by the bioextracts, which ionize on contact with the water to be treated (Aragaw et al., 2021). This ionization led to an increase in the minerals present in the water, notably the major cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}. The increase in Ca^{2+} and Mg^{2+} therefore led to an increase in the water's hydrotimetric titre (HT), all the more so as some studies have shown that Boscia and Aloe extracts are rich in calcium and magnesium minerals (Adlakha et al., 2022; Kim et al., 1997).

In contrast to cations, a slight decrease in the concentration of major anions HCO^{3-}, SO42- and Cl- was observed during treatment of water samples with the Boscia/Aloe mixture. This decrease can be explained by the release of proteins and various cationic polyelectrolytes contained in the bioextracts, which once in the raw water will bind to the negatively charged mineral particles, thus promoting their removal by adsorption through electrostatic interactions (Das et al., 2022; Rossi et al., 2024).

Microbiological analysis of water samples treated with the mixture revealed highly promising results, particularly for the reduction of *Escherichia coli*, total coliforms and enterococci. Indeed, the combined effect of Boscia and Aloe extracts resulted in an average reduction of 95–100% in these microbial indicators after water treatment. These significant results support the idea that *Boscia senegalensis* and *Aloe vera* extracts possess effective antimicrobial properties against Gram-negative and Gram-positive bacteria (Arbab et al., 2021; Vougat Ngom and Foyet, 2022). The majority of physicochemical and microbiological parameters of water treated with the Boscia/Aloe mixture met WHO-recommended potability standards during this study. However, it's important to note that if the treated water is stored at room temperature for an extended period (12 to 48 h), a renewed bacterial proliferation may occur (Konkobo et al., 2023). This can be attributed to the fact that, over a long storage time, the organic matter from the bioextracts present in the water may serve as nutrients for the bacteria that escaped the initial treatment. To reduce the risk of bacterial proliferation, additional simple disinfection methods can be implemented after treatment of raw water with Boscia/Aloe mixture. These are the boiling method; the SODIS method; and sand filtration (Konkobo et al., 2024). Among these options, boiling the treated water is a widely recognized and easy-to-implement method for destroying remaining microorganisms and breaking down residual organic matter (Ajiboye et al., 2021). Exposing water to solar disinfection, known as the SODIS (Solar Disinfection) method, also offers a practical and affordable alternative, particularly in sunny regions. This method uses the sun's ultraviolet rays to inactivate bacteria and other pathogens, while reducing the organic matter present in the water (García-Gil et al., 2021). Finally, sand filtration is another technique that eliminates both organic matter and remaining micro-organisms, guaranteeing water of higher microbiological quality (Kauppinen et al., 2014). So, by combining one of these techniques after treating water with the Boscia/Aloe mixture, it is possible to extend the shelf life of treated water while minimizing the risk of secondary contamination.

5 Conclusion

This study demonstrated the effectiveness of *Boscia senegalensis* seeds powder and *Aloe vera* leaves in the potabilization of water intended for human consumption. In view of the results obtained, the application prospects for this biocoagulant/bioflocculant mixture are promising, particularly in rural areas and developing countries where water treatment resources are limited. The ease of extraction and availability of *Boscia senegalensis* seeds and *Aloe vera* leaves are major assets for large-scale adoption. Moreover, local production of these biocoagulants could stimulate the local economy and promote sustainable practices.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

FK: Conceptualization, Investigation, Methodology, Writing – original draft. MnD: Methodology, Writing – review & editing, Formal analysis. EO: Formal analysis, Methodology, Writing – review & editing. PB: Methodology, Writing – review & editing, Investigation, Supervision, Validation, Visualization. BS: Data curation, Methodology, Writing – review & editing. SZ: Methodology, Project administration, Software, Writing – review & editing. NR: Methodology, Visualization, Writing – review & editing. RD: Formal analysis, Methodology, Visualization, Writing – review & editing. AS: Methodology, Writing – review & editing. KK: Methodology, Writing – review & editing. DB: Formal analysis, Methodology, Visualization, Writing – review & editing. PS: Supervision, Validation, Visualization, Writing – review & editing. MHD: Funding acquisition, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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