

Research Article.

Evaluation of the antimicrobial activities of a marine macroalgae from the West Coast of Tipaza

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ABSTRACT

In order to enhance the value of aquatic biomass from the Algerian coast, we evaluated the antimicrobial activities of marine algae collected from the Algerian coast. The species *Sargassum vulgare* was harvested in the Tipaza region (Kouali Beach). The extraction was performed using maceration in a water-ethanol mixture. The results indicate a crude extract yield of 12.9%. The antibacterial activity was assessed using the agar diffusion method. The results showed a complete absence of inhibitory effect against the seven tested strains: *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922, *Enterococcus faecalis* ATCC 29212, *Pseudomonas aeruginosa* ATCC 27853, *Klebsiella pneumoniae* ATCC 700603, *Klebsiella oxytoca* and *Enterobacter*, collected from urine samples (ECBU). However, the extract exhibited antifungal activity, with mycelial growth inhibition percentages of 57.14%, 63.63%, and 64.28% against *Fusarium equiseti*, *Umbelopsis ramanniana*, and *Penicillium expansum*, respectively.

KEYWORDS

Antimicrobial activity;
Macroalgae;
Sargassum vulgare;
Extraction;
Antifungal activity.

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1 INTRODUCTION

The ocean covers 70% of the Earth's surface and harbors up to 90% of our planet's organisms. This vast environment hosts a diversity of unique ecosystems and rich resources. Many marine organisms possess significant potential for producing bioactive compounds used in pharmaceutical, nutraceutical, and cosmetic applications. Among these organisms, algae stand out due to their remarkable diversity and ability to synthesize a multitude of bioactive substances (Zhang *et al.*, 2023).

Algae play a crucial ecological role. They form the foundation of food webs, provide oxygen that enables aquatic organisms to breathe, absorb CO₂, and offer shelter and habitat to hundreds of species (González Fernández *et al.*, 2023). Currently, over 20000 algal species have been identified and classified into different categories: green algae (Chlorophyceae), brown algae (Phaeophyceae), and red algae (Rhodophyceae). Brown algae account for approximately 59% of all cultivated macroalgae worldwide, followed by red algae (40%) and green algae (less than 1%). Furthermore, algae are responsible for about 40-50% of Earth's annual photosynthesis, significantly contributing to greenhouse gas emission reduction (Wang *et al.*, 2015).

Algae are renowned for their ability to produce various secondary metabolites, including phenolic acids, flavonoids, tannins, saponins, steroids, triterpenoids, alkaloids, and hydroquinones. These compounds are known for their beneficial properties, such as antioxidant, antimicrobial, anti-inflammatory, antitumor, anticancer, antiviral, and antidiabetic activities (Meiyasa *et al.*, 2024).

Sargassum is a genus of brown macroalgae (class Phaeophyceae) in the order Fucales, comprising over 400 species found in tropical and subtropical regions worldwide. They grow subtidally, attaching to coral, rocks, or shells in moderately exposed or sheltered rocky/gravelly environments. These tropical populations frequently undergo seasonal growth and collapse cycles in response to sea temperature fluctuations. These algae have garnered particular attention as medicinal foods due to their high nutritional value and health benefits (Sabzi *et al.*, 2023; Abu Ahmed *et al.*, 2021). *Sargassum vulgare* has been identified as a potential source of a wide range of natural compounds, such as alginate, fucans, sulfated polysaccharides, and polyphenols, which exhibit diverse biological activities (Nawaim *et al.*, 2017).

Although *S. vulgare* is widespread in the Atlantic's tropical/subtropical zones (*e.g.*, Azores, Canary Islands) and the Mediterranean, its diversity along Algeria's 1600 km coastline is understudied. Existing research has been limited to central coastal sites (Chouh *et al.*, 2022).

Seaweeds are valuable marine plants that have garnered significant public attention due to their richness in bioactive compounds, nutrients, and minerals. They have been widely utilized in cosmetic, nutraceutical, and pharmaceutical applications (Taher *et al.*, 2021). The biochemical composition of seaweeds varies considerably depending on species, season, growth conditions, and stress factors. However, most bioactive compounds described have been isolated from red and brown algae, while green algae remain a relatively underexplored field of investigation (Person, 2011).

The biosynthetic intermediates responsible for secondary metabolite formation yield final products categorized into three major classes: terpenes (lipid derivatives), alkaloids (amino acid-derived protein components), and phenols (carbohydrate derivatives) (El-Beltagi *et al.*, 2019). Phenols (or phenolic compounds) are a class of chemical compounds characterized by a hydroxyl group (-OH) bonded to an aromatic hydrocarbon ring (Holdt and Kraan, 2011). Polyphenols are typically classified into categories and subcategories based on their chemical structures, particularly the number of phenolic rings they contain and their associated structural elements (Jimenez-Lopez *et al.*, 2021).

The emergence of bacterial strains resistant to conventional antibiotics has necessitated the urgent search for novel bioactive compounds (Chbani *et al.*, 2011). Marine algae harbor diverse antibacterial agents, including amino acids, terpenoids, phlorotannins, phenolic compounds, steroids, halogenated ketones, alkanes, and fatty acids (Mtolera and Semesi, 1996; Afzal *et al.*, 2022).

Free radicals have been established as key mediators of biomolecular oxidation (Kim and Pangestuti, 2011). Seaweeds represent one of the richest natural sources of antioxidants, with phlorotannin, sulfated polysaccharides (*e.g.*, fucoidans), and carotenoids being particularly noteworthy (Hermund, 2018). Importantly, marine algae produce both antibacterial and antifungal compounds, demonstrating their dual therapeutic potential (Afzal *et al.*, 2022).

Growing concerns exist regarding the adverse effects associated with synthetic compounds used to combat oxidative stress and microbial infections. This has created a critical need to

explore alternatives to synthetic antioxidants and conventional antibiotics. Seaweed-based therapies represent a viable option within primary healthcare systems, positioning them as a highly promising pathway for advancing improved traditional medicines (Ben Abdallah *et al.*, 2019).

The Algerian Mediterranean coast hosts unique seaweed species whose study may lead to the discovery of novel therapeutic agents for human diseases (Mellouk *et al.*, 2017). Within this context, the present research work aims to investigate the effects of crude extracts from brown marine seaweed collected along Algeria's western coast on antibacterial and antifungal activities.

2 MATERIALS AND METHODS

2.1 Sampling sites

Seaweed samples were collected in April 2024 from Kouali Beach (36°38'N, 2°48'E), a Mediterranean coastal site located 4.1 km east of Tipaza city center, Algeria (Figure 1). The study site was georeferenced using Google Earth Pro (v. 7.3.6; Google LLC, 2024). This rocky intertidal zone (mean April water temp: 18.5±1.2 °C; salinity: 37.2 psu) lies within the Mediterranean biogeographic province (Spalding *et al.*, 2007).

2.2 Biological Material

The microbial strains used in microbiological assays comprised two groups of microorganisms: phytopathogenic fungi and bacteria, as detailed in Tables 1 and 2. The seven tested bacterial strains were provided by the Tipaza Public Health Laboratory (Algerian Ministry of Health, reference lab code: LAB/TPH/2024-001).



Figure 1. Geographical location of sampling stations

Table 1. Bacterial strains used for antibacterial testing

Strain Code	Species	Source	Gram Stain	ATCC/MTCC No.	Clinical Relevance
LAB-TP001	<i>Staphylococcus aureus</i>	Clinical isolate	Gram+	ATCC 25923	MRSA control
LAB-TP002	<i>Escherichia coli</i>	Environmental sample	Gram-	MTCC 443	UTI pathogen
LAB-TP003	<i>Pseudomonas aeruginosa</i>	Wound swab	Gram-	ATCC 27853	Biofilm former
LAB-TP004	<i>Enterococcus faecalis</i>	Food contamination	Gram+	ATCC 29212	Vancomycin resistance
LAB-TP005	<i>Klebsiella pneumoniae</i>	Sputum sample	Gram-	ATCC 700603	ESBL producer
LAB-TP006	<i>Salmonella Typhimurium</i>	Water sample	Gram-	ATCC 14028	Foodborne pathogen
LAB-TP007	<i>Bacillus subtilis</i>	Soil isolate	Gram+	ATCC 6633	Quality control strain

Table 2. Fungal strains used for antifungal testing

Strain Code	Species Name (Corrected)	Taxonomic Authority	Morphology	Risk Group	Application Relevance
X3	<i>Umbelopsis ramanniana</i>	(Möller) Arx 1984	Mucoralean	RG-1	Industrial enzyme production
X8	<i>Fusarium equiseti</i>	(Corda) Sacc. 1886	Hyphae	RG-2	Phytopathogen (cereal diseases)
X13	<i>Penicillium expansum</i>	Link 1809	Conidial	RG-1	Postharvest fruit spoilage

2.3 Sample processing protocol

2.3.1 Field collection

During low tide, between 09:00 and 11:00 am, algal specimens were manually harvested to ensure optimal collection conditions. Immediately after harvesting, the specimens were placed in sterile containers moistened with

seawater to preserve their freshness and prevent desiccation.

2.3.2 Cleaning Procedure

The collected algal specimens underwent a three-step cleaning process to ensure the removal of impurities. Initially, a primary wash was performed by rinsing the samples three times with filtered seawater (using a 1µm filter) to eliminate epibionts. This was followed by a

secondary rinse using tap water with a pH of 7.2±0.3, applied for five minutes under constant agitation to dislodge any remaining particles. Finally, a thorough rinse with distilled water was conducted to ensure complete removal of salts and residual contaminants.

2.3.3 Drying process

The sample was air-dried in darkness at a temperature of 20±2 °C and 35% relative humidity for 7 days. It was then monitored until it reached a constant weight, with a moisture content of no more than 5%, as determined by gravimetry.

2.3.4 Powder preparation

The dried material was mechanically ground using an IKA® A11 mill to achieve a particle size of 50–100 µm. The resulting powder was stored in amber glass vials at 4°C to preserve its stability.

2.3.5 Preparation of the crude extract

A solution of 80 mL ethanol and 20 mL distilled water was added to 20 g of algal powder. The mixture was then stirred using a propeller agitator for 15 minutes at room temperature, protected from light to prevent oxidation. A second homogenization step was performed for 90 minutes using an ultrasonic homogenizer. The extract was filtered through Whatman No. 01 filter paper. The filtrate was collected, and the residue underwent a third homogenization with 80 mL ethanol and 20 mL distilled water for 90 minutes using an ultrasonic homogenizer. The extract was then filtered again through Whatman No. 01 filter paper, and the filtrate was combined with the previously obtained fraction.

After solvent evaporation using a rotary evaporator, the dry residue was reconstituted in

10 mL DMSO for antimicrobial activity testing. The extract was then centrifuged at 4000 rpm for 10 minutes. Finally, the extract was stored at 4°C for further biological activity studies (modified from Gourguillon *et al.*, 2016).

2.3.6 Yield calculation of the dry extract

The yield of the dry extract was determined using Equation 1 (Nabti *et al.*, 2023).

$$R (\%) = \frac{P_1 - P_2}{P_3} \times 100 \quad (\text{Eq. 1})$$

Where **R** is the yield of the dry extract (%); **P₁**: Weight of the flask after evaporation; **P₂**: Weight of the flask before evaporation; **P₃**: Weight of the dry algal material.

2.4 Evaluation of Antibacterial Activity (Aromatogram)

2.4.1 Principle

The antibacterial properties of marine algae were evaluated using the agar diffusion method (the aromatogram) (Ben Abdallah *et al.*, 2019). This method involves placing a sterile 6 mm diameter disk impregnated with the extract onto an agar medium previously inoculated with a microbial culture. After incubation, the results were assessed by measuring the diameter of inhibition zones (in millimeters). The experiment evaluates the inhibition zones around disks placed on a bacterial colony (Boutabia *et al.*, 2016).

2.4.2 Inoculum Preparation and Seeding

After 24 hours, several colonies from a pure culture were collected with a loop and transferred into sterile test tubes containing 5 mL of sterile physiological saline (NaCl). Prepared and solidified Mueller-Hinton plates were then

inoculated by swabbing with sterile cotton swabs dipped in the respective bacterial suspensions.

2.4.3 Disk Application

Following drying of the inoculated Mueller-Hinton (MH) plates, sterile forceps were used to carefully place 6 mm cellulose disks on the surface of each MH agar plate. Using a micropipette, 20 µl of algal extract was dispensed onto each disk. Control disks were impregnated with dimethyl sulfoxide (DMSO) to serve as a negative control, confirming the absence of antimicrobial activity from DMSO alone.

An antibiotic susceptibility test was subsequently performed. As positive controls, four antibiotic disks—ampicillin (10 µg), cefoxitin (30 µg), netilmicin (30 µg), and cefazolin (30 µg)—were placed on each bacterial strain to compare the antibacterial effect of the prepared extract with that of known antibiotics. All prepared plates were then incubated at 37 °C for 24 hours.

2.4.4 Interpretation of Results

Based on the inhibition zone diameters, bacterial susceptibility was classified as follows (Ponce *et al.*, 2003).

Table 3. Antibacterial activity evaluation scale (Ponce *et al.*, 2003)

Inhibition zone diameter (mm)	Strain susceptibility
D < 6	Resistant
9 ≤ D ≤ 14	Sensitive
15 ≤ D ≤ 19	Highly sensitive
D ≥ 20	Extremely sensitive

2.5 Evaluation of Antifungal Activity

2.5.1 Fungal Strain Subculturing

A fragment was aseptically collected from the target purification zone using a scalpel. It was

placed at the center of a Petri dish containing Sabouraud agar supplemented with chloramphenicol. Each Petri dish was labeled with the strain code and date. Incubation was repeated until a pure culture was obtained.

2.5.2 Antifungal Activity Assessment by Direct Contact Technique

A 1000 µL aliquot of *Sargassum vulgare* extract was transferred to a sterile Petri dish, mixed with 18–20 mL of chloramphenicol-supplemented Sabouraud agar, homogenized thoroughly, and allowed to solidify. After solidification, a 10 mm fungal plug from a 7-day-old mother culture was aseptically excised using a sterile scalpel and placed inverted at the center of the agar plate. An extract-free plate served as the negative control. All plates were incubated at 25 °C for 7 days (modified from Alilou *et al.*, 2007).

2.5.3 Data Analysis

Post-incubation, mycelial growth diameters (mm) were measured. Relative to the control's mycelial growth, the inhibition percentage was calculated using the formula from De Billerbeck *et al.* (2001) and Pandey *et al.* (1982):

$$\% \text{ Inhibition} = \frac{D_c - D_t}{D_c} \times 100 \quad (\text{Eq. 2})$$

Where: **D_c**: Mycelial diameter of control; **D_t**: Mycelial diameter of treatment.

$$\% \text{ Inhibition} = \frac{d_c - d_t}{d_c} \times 100 \quad (\text{Eq. 3})$$

Where, **PI**: Percentage inhibition; **dc**: Mycelial diameter of control (measured value - 10 mm initial plug diameter); **dt**: Mycelial diameter of treatment (measured value - 10 mm initial plug diameter)

2.5.4 Antifungal Activity Assessment

The antifungal activity of the algal extract was evaluated based on radial growth inhibition percentages (%) according to Hajji (2016); see Table 4.

Table 4. Antifungal activity evaluation scale (Ponce *et al.*, 2003)

Inhibition %	Activity Level
30–40%	Weak activity
50–60%	Moderate activity
60–70%	Good activity
>70%	Excellent activity

3 RESULTS

3.1 Extraction Yield

Maceration of 20 g of *S. vulgare* powder in a hydroethanolic solution (80:20, v/v) yielded a dry extract characterized by a dark green to light brown coloration, a powdery texture, and a pungent odor.

3.2 Yield Calculation

The extraction yield was determined relative to the initial dry plant material. The yield percentage was calculated as follows:

$$R (\%) = [(P_1 - P_2) / P_3] \times 100 = [(383.92 \text{ g} - 381.34 \text{ g}) / 20 \text{ g}] \times 100 = 12.9\%$$

3.3 Antibacterial Activity

The antibacterial potential was assessed using the standard disk diffusion assay (Ben Abdallah *et al.*, 2019). This preliminary screening method evaluates extract capacity to inhibit microbial growth through measurement of inhibition zone diameters (mm) around impregnated disks, performed with calibrated digital calipers (Fertout-Mouri *et al.*, 2016).

The disk diffusion assay revealed that *Sargassum vulgare* extract exhibited no detectable antibacterial activity against any of the tested bacterial strains. No inhibition zones were observed for the algal extract. We noticed a complete absence of growth inhibition compared to positive controls.

3.4 Antibiotic Controls (showing expected activity)

The *S. vulgare* extract showed no detectable activity against any tested strains; the DMSO control confirmed no solvent interference. Whereas Netilmicin demonstrated broad-spectrum activity (+++ against all strains). There are variable susceptibility patterns observed for other antibiotics (Tab. 5).

Table 5. Antibacterial activity evaluation of *Sargassum vulgare* extract compared to reference antibiotics

Tested Bacteria	Inhibition Zone Diameter (mm)					
	Extract	DMSO	AMP	CXN	CZN	NET
<i>Staphylococcus aureus</i>	-	-	+++	++	+++	+++
<i>Enterococcus faecalis</i>	-	-	+++	-	++	+++
<i>Escherichia coli</i>	-	-	-	+++	-	+++
<i>Pseudomonas aeruginosa</i>	-	-	+++	-	-	+++
<i>Klebsiella pneumoniae</i>	-	-	+	-	-	+++
<i>Klebsiella oxytoca</i>	-	-	-	-	-	+++
<i>Enterobacter spp.</i>	-	-	+	-	-	+

(-) No inhibition (resistant); (+) 6-10 mm (weak activity); (++) 11-15 mm (moderate activity); (+++) >15 mm (strong activity). **AMP:** Ampicillin (10 µg); **CXN:** Cephalexin (30 µg); **CZN:** Cefazolin (30 µg); **NET:** Netilmicin (30 µg)

3.5 Quantitative Analysis of Antibiotic Activity

As shown in Figure 2, the *S. vulgare* extract demonstrated no detectable activity against any tested strain (0 mm zones), while netilmicin

(NET) showed universal efficacy. Strain-specific susceptibility patterns were observed for other antibiotics.

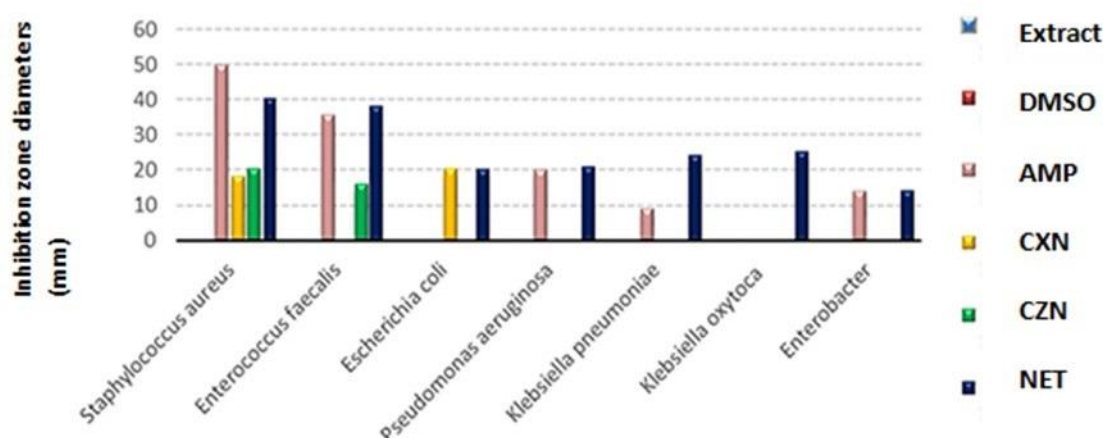


Figure 2. The inhibition zone diameters

3.6 Antifungal Activity

After 7 days of incubation at 25°C, the fungi *Fusarium equiseti*, *Umbelopsis ramanniana*, and *Penicillium expansum* treated with the hydro-ethanolic extract of *Sargassum vulgare* exhibited reduced mycelial growth compared to the control. The results are presented in Figure 4.

According to Figure 4, the antifungal activity results revealed significant variation in the inhibition rate depending on the fungal strain tested. For *Fusarium equiseti*, the extract inhibited mycelial growth by 57.14%, indicating moderate efficacy against this strain. In contrast, the strains *Penicillium expansum* and *Umbelopsis ramanniana* exhibited strong antifungal activity, with inhibition rates of 64.28% and 63.63%, respectively.

4 DISCUSSION

Limited research exists on the antioxidant and antimicrobial properties of algae, which

prompted our investigation into these characteristics in the brown seaweed *Sargassum vulgare*. Preliminary results demonstrate this macroalga's significant potential as an antifungal agent. These findings could be further validated through additional *in vivo* and *in vitro* biological assays to identify promising natural sources for therapeutic applications.

The hydroethanolic extraction of *Sargassum vulgare* crude powder via maceration yielded 12.9%, indicating good extraction efficiency. This finding aligns with previous work by Tannoury *et al.* (2016), who reported that the ethanol-water extract yield of *S. vulgare* (20.04%) was substantially higher than the ethanol-chloroform extract yield (3.53%).

Multiple factors influence the yield of secondary metabolite extraction, including the duration of plant material drying, the particle size of the ground material, and the ethanol percentage in the hydroethanolic solvent.

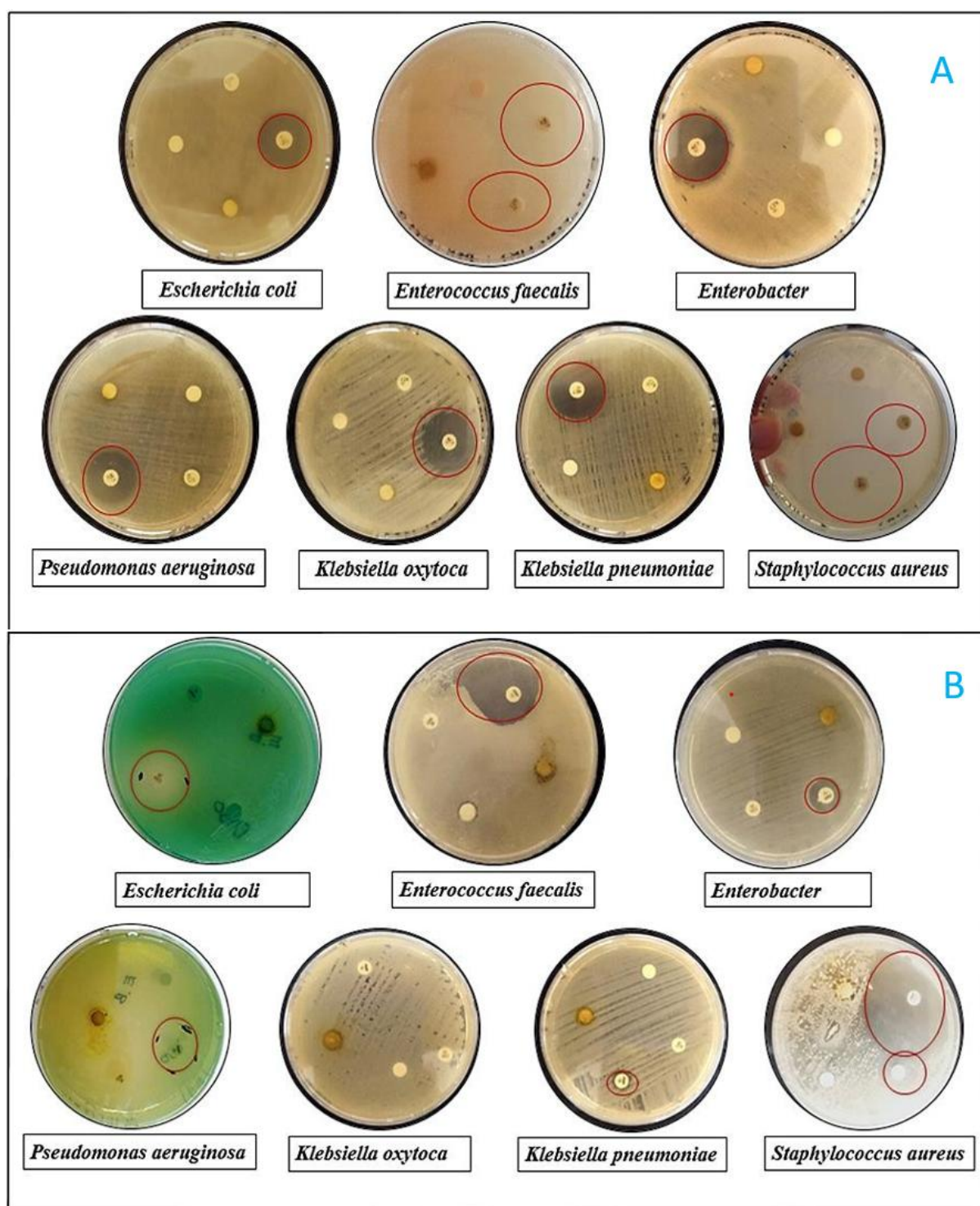


Figure 3. Antibacterial activity assessment of *Sargassum vulgare* extract compared to reference antibiotics (netilmicin and cefazolin) via disk diffusion assay. **(A)** Representative plates showing inhibition zones. **(B)** Quantitative comparison of zone diameters (mm) across tested bacterial strains

In addition, the solvent-to-solid ratio, maceration time, and agitation speed can affect the extraction yield. Notably, hydroethanolic solvent is widely employed for plant secondary metabolite extraction due to its similarity to water traditionally used in herbal medicine (Koné *et al.*, 2017).

The antibacterial activity of the marine alga *Sargassum vulgare*, collected in April 2024 from the coastal region of Tipaza, was evaluated using the solid medium diffusion method. The extract was prepared using ethanol-water as solvent. Testing was conducted against: (1) Gram-negative bacteria: *Escherichia coli*, *Pseudomonas aeruginosa*; (2) Gram-positive bacteria: *Staphylococcus aureus*, *Klebsiella oxytoca*, *Enterobacter* sp., *Enterococcus faecalis*, *Klebsiella pneumoniae*

The *Sargassum vulgare* extract showed no antibacterial activity against the tested bacterial strains. Our findings are consistent with several previous studies. Chiheb *et al.* (2009) reported that methanolic extracts of *S. vulgare* exhibited no antibacterial activity against *Staphylococcus aureus*. González-Mendoza *et al.* (2018) observed no inhibitory effects when testing *S. vulgare* extracts against *Bacillus cereus*. However, contrasting results were reported by Mohamed Elanwar *et al.* (2010), who demonstrated strong inhibitory activity of acetone extracts from *S. vulgare* against six microorganisms (*B. subtilis*, *S. aureus*, *E. coli*, *K. pneumoniae*, and *C. albicans*). Additionally, Mtolera and Semesi (1996) found that extracts from the alga *Caulerpa mexicana* showed no activity against reference strains including *Bacillus subtilis* (V5007), *Staphylococcus aureus* (NCTC 6571), and *Escherichia coli* (NCTC 10418).

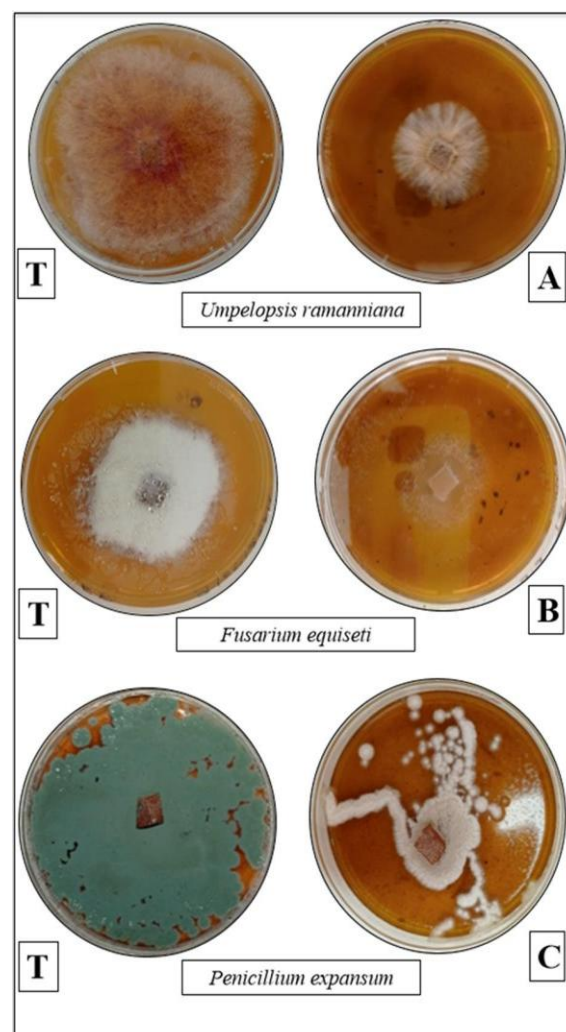


Figure 4. Antifungal effect of the crude extract (*Sargassum vulgare*) using the direct contact technique against fungal strains. A, B, C: Treated with 1000 μ L of extract; T: Untreated control

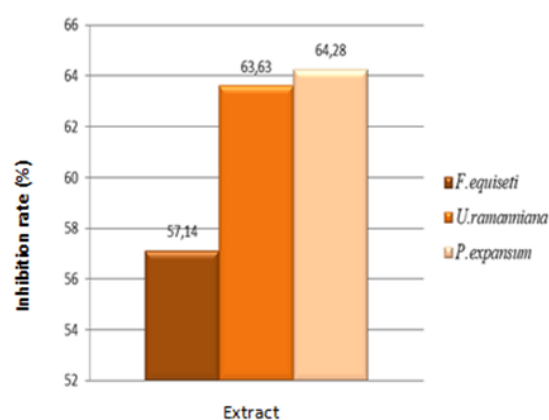


Figure 5. Effect of the hydroethanolic extract from *Sargassum vulgare* on fungal strain growth

Multiple variables were identified as potential determinants of algal antibacterial activity, including environmental conditions and collection period, growth stage of the algal specimens, experimental methodologies, and extraction and processing techniques, which are considered as factors influencing antibacterial activity of algae. While various solvents have been employed to assess the antimicrobial potential of marine algae, current research has not yet established an optimal solvent system for algal extraction. Several studies have systematically compared different solvent systems to evaluate their extraction efficiency and antimicrobial activity detection capabilities (Manivannan *et al.*, 2011).

The antibiotic susceptibility testing revealed that *Staphylococcus aureus* (Gram-positive) showed the highest sensitivity to antibiotics, as evidenced by significantly larger inhibition zones compared to other tested strains. The observed variations in antibacterial activity can be attributed to fundamental differences in cellular structure between Gram-positive and Gram-negative bacteria. Gram-negative bacteria possess a complex, multilayered cell wall that significantly impedes the penetration of active compounds into bacterial cells, thereby enhancing microbial resistance to antibiotics (Arguelles *et al.*, 2019). This structural characteristic may explain the differential sensitivity to algal extracts observed in our study.

Antimicrobial substances are defined as chemical agents that either kill microorganisms or inhibit their growth, encompassing antibiotics and other antibacterial or antifungal compounds. However, growing consumer concerns about synthetic food additives have driven increased interest in

natural alternatives, particularly those derived from marine sources (Ben Abdallah *et al.*, 2019).

Marine algae synthesize numerous secondary metabolites with diverse biological properties, making them a valuable source of bioactive compounds. Phytochemical analyses have revealed that chlorophyta (green algae), phaeophyta (brown algae), and rhodophyta (red algae) contain chemical constituents exhibiting: Cytostatic effects, Antiviral activity, Anthelmintic properties, Antioxidant capacity, Antibacterial action and Antifungal potential.

The observed antifungal activity particularly suggests that marine algae produce bioactive secondary metabolites with therapeutic relevance. This finding is particularly significant given the urgent need for novel antifungal agents to treat life-threatening infections, as current antifungal medications are frequently limited by either toxicity or insufficient efficacy (Lavanya and Veerappan, 2012).

Our results demonstrate that the hydroalcoholic (ethanol-water) extract of *Sargassum vulgare* exhibited significant antifungal activity against *Fusarium equiseti*, *Umbelopsis ramanniana*, and *Penicillium expansum*. These findings align with previous research by Nawaim *et al.* (2017) in Tunisia, who reported that aqueous and methanolic extracts of *S. vulgare* effectively inhibited mycelial growth of *Fusarium sambucinum* and *F. solani*.

Furthermore, González-Mendoza *et al.* (2018) demonstrated that silver phytonanoparticles (AgNPs) synthesized from *S. vulgare* aqueous extract showed substantial antifungal efficacy: 70% inhibition against *Fusarium solani*, and 55.05% inhibition against *Alternaria alternate*.

Jimenez-Lopez *et al.* (2021) identified potent antifungal activity of dieckol and eckol (purified from *Ecklonia cava*) against *Trichophyton rubrum*. Phycobiliproteins (PBPs) from *Hydropuntia cornea* effectively controlled gray mold (*Botrytis cinerea*) in tomato fruits at concentrations of 2.4 and 4.8mg/mL (Jiménez-González *et al.*, 2023). Aqueous extracts of *Halopitys incurvus* and *Stypocaulon scoparium* inhibited *Fusarium oxysporum* f. sp. *albedinis* by 61% and 60%, respectively (Khelil-Radji *et al.*, 2017).

Naja *et al.* (2012) reported contrasting results in their investigation of algal extracts. No antifungal activity was detected in either the crude extract or fractions (petroleum ether, ethyl acetate, butanol, aqueous) of *Sargassum vulgare*. Significant activity was observed in the ethyl acetate extract of *Padina pavonica* against *Candida glabrata* and *Candida krusei*. Ben Abdallah *et al.* (2019) demonstrated differential antifungal effects among algal species such as Brown algae (*Dictyota dichotoma* and *Cystoseira crinita*) with positive activity against *Saccharomyces cerevisiae* and *Aspergillus niger*, or Green algae (*Flabellia petiolata* and *Anadyomene stellata*), which exhibited no detectable activity.

The antifungal properties of marine algae are mediated by bioactive compounds, particularly phlorotannins, which inhibit fungal cell wall biosynthesis, disrupt essential fungal enzymes, and impair fungal growth and development. Multiple ecological factors significantly influence the antifungal potential of marine algae, particularly through their effects on secondary metabolite production. The climate-mediated parameters that modulate algal biochemical pathways (Farid *et al.*, 2020) include the

environmental variables, such as temperature fluctuations, solar radiation intensity, nutrient availability, and salinity gradients. In addition to climatic factors, as seasonal variations, ocean current patterns, precipitation regimes and extreme weather events.

5 CONCLUSIONS

The marine environment represents a vast resource for discovering novel bioactive compounds with potential therapeutic applications. Macroalgae, particularly brown seaweeds, are among the most prolific producers of biologically active secondary metabolites. This study investigated the antimicrobial properties of the brown alga *Sargassum vulgare* collected from the coastal region of Tipaza, Algeria. The study showed an interesting antifungal activity, while no significant antibacterial effect was noticed. These results suggest that *Sargassum vulgare* could be a promising source of natural fungicides for post-harvest protection. However, investigations should be continued to assess the antimicrobial potential of marine algae, and an optimal solvent system for algal extraction should be evaluated for its extraction efficiency and antimicrobial activity detection capacity. Then, further analyses should be conducted to identify and characterize the active compounds responsible for the observed biological activity. This would strengthen the findings and provide more detailed insights into the potential applications of *Sargassum vulgare* as a natural fungicide.

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