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Antibacterial potential of extracts of *Asparagopsis armata*, a red marine alga, against multidrug-resistant *Escherichia coli* in urinary tract infections.

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Urinary tract infections (UTIs) primarily caused by *Escherichia coli* are a global public health concern exacerbated by rising antibiotic resistance, particularly in Algeria, where multidrug-resistant strains dominate clinical isolates. This study investigates the antibacterial potential of *Asparagopsis armata*, a red marine alga, against UTI pathogens in Algeria, particularly Ghardaia Region. Also, the LC-MS/MS analysis was realized to identify 28 phenolic compounds in the methanol extract. Data from 5,084 urine samples revealed 23% UTI prevalence, with *E. coli* accounting for 61% of isolates, while females (26%) exhibited higher infection rates than males (16%). Methanol extracts yielded the highest bioactivity (3.71% via ultrasonic assisted extraction) and exhibited the strongest antibacterial activity, with minimal inhibitory concentrations (MICs) of 119 to 123 µg/mL against 11 multidrug resistant *E. coli* strains. All extracts inhibited all tested strains. This study demonstrates the potential of *A. armata* as a sustainable alternative to conventional antibiotics, supporting marine-derived antimicrobials as a critical strategy to combat antibiotic resistance.

Keywords: *Asparagopsis armata*; urinary tract infections; *Escherichia coli*; methanol and acetone extracts; LC-MS/MS analysis.

Introduction

Urinary tract infections (UTIs) represent one of the most prevalent types of infections globally, affecting millions of individuals each year. As highlighted by the World Health Organization, UTIs pose a significant public health challenge, particularly in developing countries, and are among the leading infections encountered in primary and acute care settings. The global incidence of UTIs is increasing, with an estimated 8.6 million healthcare visits attributed to these infections annually (Horváth et al., 2020).

Compounding this issue, antibiotic resistance has escalated to alarming levels worldwide. Projections indicate that, by 2050, antimicrobial resistance could result in 10 million deaths annually and lead to a $100 trillion loss in the global economy unless concerted efforts are undertaken to mitigate this growing threat (Aouf et al., 2018). In Algeria, the incidence of UTIs has risen substantially since the early 1990s, particularly in vulnerable healthcare environments such as intensive care units and surgical wards (Amiri et al., 2025). Additionally, numerous studies have documented the concerning emergence of multidrug-resistant bacterial strains within the country (Yagoubat et al., 2017). This challenge is especially pronounced with Gram-negative bacilli, which constitute a significant proportion of microbial pathogens (Breijyeh et al., 2020), with *Escherichia coli*, *Klebsiella pneumoniae*, *Proteus mirabilis*, and *Enterococcus faecalis* being the most prevalent species (Khan et al., 2020).

The escalating global burden of antibiotic resistance has rendered the discovery of novel antimicrobial agents an urgent priority. Current therapeutic options for UTIs face significant limitations, including the emergence of the multidrug-resistant pathogens, adverse side effects, and narrow spectra of activity (Salam et al., 2023). For instance, conventional antibiotics often fail to address infections caused by resistant Gram-negative bacteria such as *Escherichia coli* which dominate UTI etiologies. Furthermore, the reliance on existing antibiotics has led to unavoidable resistance development, necessitating the exploration of alternative strategies to combat these pathogens (Uddin et al., 2021). Marine-derived natural products, such as those from red algae, represent a promising avenue for discovering novel antimicrobial compounds (Bharathi et al., 2024).

Asparagopsis armata, a species of marine microalgae has garnered attention for its potential to produce bioactive metabolites with antimicrobial properties (Pinteus et al., 2020; Maidi et al., 2025). To date, no prior studies have investigated the antimicrobial potential of *Asparagopsis armata* from Algerian coastal waters against clinically isolated UTIs pathogens. Additionally, gaps persist in understanding the aetiology of UTIs in the study region. This study addresses these gaps by evaluating the antimicrobial activity of *A. armata* extracts. This offers a sustainable approach to combat UTIs in regions with high resistance burdens.

Materials and methods

We gathered data from the bacteriology service of a private laboratory Ibn Rochd, in Ghardaia Province, Algeria. The data collected focused on urine samples that had been analyzed by the laboratory, and information was collected on an opening sheet which included: first and last names, age, sex, the analyses performed with their results (positive / negative, the isolated microorganism, antibiotic susceptibility of the microorganism). Data was used to gain insights about the current situation of urinary tract infections in the study region, and to determine the most prevalent causative agents of these infections.

Samples of the red algae *A. armata* Harvey were harvested by hand picking in March 2023 from the region called Salamandre (35°54'49" N, 0°03'11" E) in Mostaganem city, the Western Mediterranean coast of Algeria (Fig. 1) during a dive that reached a maximum depth of 8 meters. The harvested algae were then placed in plastic bags containing sea water and transferred to the laboratory. Sand particles and exogenous matter was removed using fresh water and the clean algae material was dried at room temperature for five days and ground to fine powder (77 g) using an electric grinder.

The extraction method by increasing polarity solvents described by Sifi et al. (2024) was used in this study. Six extracts were prepared using three extraction solvents: dichloromethane (DCM), methanol (MeOH), and acetone (ACT). For each solvent two different extraction methods were performed, Cold Maceration and Ultrasonic-Assisted Extraction (UAE). The amounts of the dry algae material and solvent volume used for each method are represented in Table 1. For

the maceration, the amount of algae material was extracted with 100 mL of each solvent and stirred (250 rpm) for 24h at room temperature. For the UAE, the solvent-algae preparations were put in a machine (Elma, Ultrasonic P) that was set to a frequency of 180 KHz at 27 °C for 60 minutes. After two filtration rounds (Whatman sterile filter paper No. 1), each solution (from both extraction methods) was concentrated to dryness at 45 °C under vacuum on a rotary evaporator (180 rpm) (Heidolph, Germany). The concentrated extracts were then recuperated in dimethyl sulfoxide (DMSO) (Sigma, Steinheim, Germany). The obtained solutions (6 solutions) were stored at 4 °C until further use.

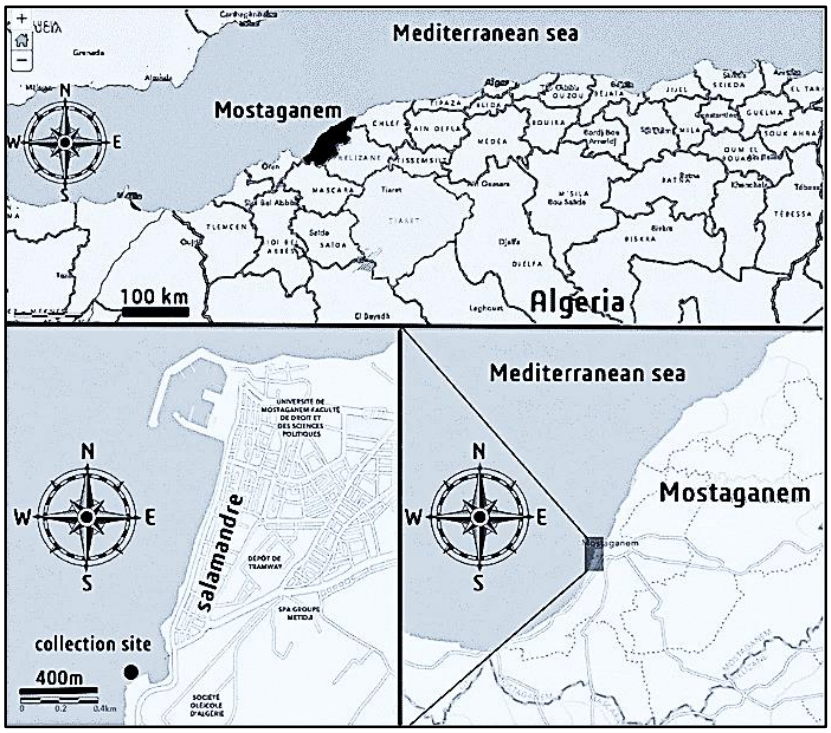

Fig. 1. Map indicating the collection site along the western coast of Algeria (Salamandre village at Mostaganem) (35°54'49" N, 0°03'11" E) (Messahli et al., 2022)

Table 1
Extraction methods and amounts of solvents used

Solvent	Method	Algae material, g	Solvent volume, mL
DCM	Maceration	16.8	100
DCM	UAE	10	100
ACT	Maceration	10	100
ACT	UAE	10	100
MeOH	Maceration	20	100
MeOH	UAE	10	100

Note: DCM – dichloromethane; ACT – acetone; MeOH – methanol; UAE – ultrasonic-assisted extraction.

A total of 11 *Escherichia coli* strains (Table 2) were provided by a private laboratory of medical analysis Ibn Rochd (Ghardaia, Algeria). The bacteriology service of the private laboratory had isolated them from infected urine samples, and found them through antibiotic susceptibility testing to be resistant to at least one class of antibiotics.

For the conservation, *E. coli* strains were cultured in Muller Hinton agar and incubated at 37 °C for 24h, after which they were transferred to Eppendorf tubes containing Muller Hinton broth and sterile 80% glycerol solution (v/v), and stored at –80 °C until use in the next steps.

Table 2
Escherichia coli strains used in this study

Strains with codes			
E. coli 19251	*E. coli* 21450	*E. coli* 1706	*E. coli* 6158
E. coli 6319	*E. coli* 21449	*E. coli* 1680	*E. coli* 6112
E. coli 6577	*E. coli* 5939	*E. coli* 1703	

The minimal inhibitory concentration (MIC) of each algal extract from both extraction methods which inhibits the growth of *E. coli* strains was determined using the micro-dilution method (Sifi et al., 2020). Each strain was prepared in a suspension of Muller Hinton broth. After 24 h of incubation at 37 °C the suspensions were adjusted to a concentration that gave an optical density between 0.08 and 0.1 McFarland in a wave length of 620 nm. 10 µL of each strain culture was added into 96 well microtitre plates containing 100 µL of the algal extract dilutions. Positive control wells containing gentamicin at different concentrations ranging from 0.19 µg/mL to 25 µg/mL and additional negative control wells involving DMSO instead of the algal extract were also included. All the prepared microtiter plates containing the strain, the algal extracts dilutions and the positive, negative controls were then incubated at 37 ◦C for 24 h. The minimal inhibitory concentration (MIC) was obtained by the addition of 40 µL of iodonitrotetrazolium chloride 0.2 mg/mL (INT) reagent to each well and inhibitory activity read after 30 min.

The LC-MS/MS analysis was performed at the Technical Platforms for Physicochemical Analysis (PTAPC) in Ouargla, Algeria. Sample extracts underwent examination utilizing a Shimadzu 8040 Ultra-High Sensitivity UPLC-ESI-MS-MS system that features UFMS technology, supported by a Nexera XR LC-20AD binary pump. The analysis was conducted using a Restek Ultra AQ C18 column, measuring 3 µm in particle size and 150 x 4.6 mm in dimensions. The electrospray ionization (ESI) parameters were set as follows: conversion dynode at -6.00 kV, interface temperature at 350 °C, collision-induced dissociation (CID) gas pressure at 230 kPa, desolvation line (DL) temperature at 250 °C, nebulizing gas flow rate at 3.00 L/min, drying gas flow rate at 15.00 L/min, and heat block set to 400 °C. The ion trap mass spectrometer operated in both negative and positive ion modes utilizing multiple reaction monitoring (MRM). A sample volume of 10 µL was injected for analysis. The mobile phase consisted of 0.1% formic acid in water for channel A and methanol for channel B, with a constant flow rate of 0.300 mL/min and the column temperature maintained at 40 °C.

The results are shown as mean ± standard deviation of three separate trials (n = 3). Significance of differences between test extracts and

control in these experiments was assessed using analysis of variance (ANOVA) and the Student t-test, with significance determined at a probability level of $P \leq 0.05$.

Results

The analysis of the collected data indicated that in the study region, approximately 23% (1,146 out of 5,084) of the patients were UT infected, the remaining 77% (3,938) showed no bacterial growth. Notably, the distribution by gender of positive UT infected was 23% (265) for male patients and 77% (881) for female patients (Fig. 2a). Among the 1,146 bacterial isolates collected (Fig. 2b), *Escherichia coli* was the most prevalent, accounting for 700 isolates (61.1%). the second most common group was the GKES group (*Klebsiella* spp., *Enterobacter* spp., and *Serratia* spp.) which collectively represented 196 isolates (17.1%), *Enterococcus* spp. ranked third, comprising 123 isolates (10.7%). In comparison, other isolates were less frequently observed: *Candida* spp. (4.1%), *Pseudomonas* spp. (2.4%), *Streptococcus* spp. (2.4%), and *Staphylococcus* spp. (1.8%). Notably, *Proteus* spp. constituted only 0.3% of the total isolates.

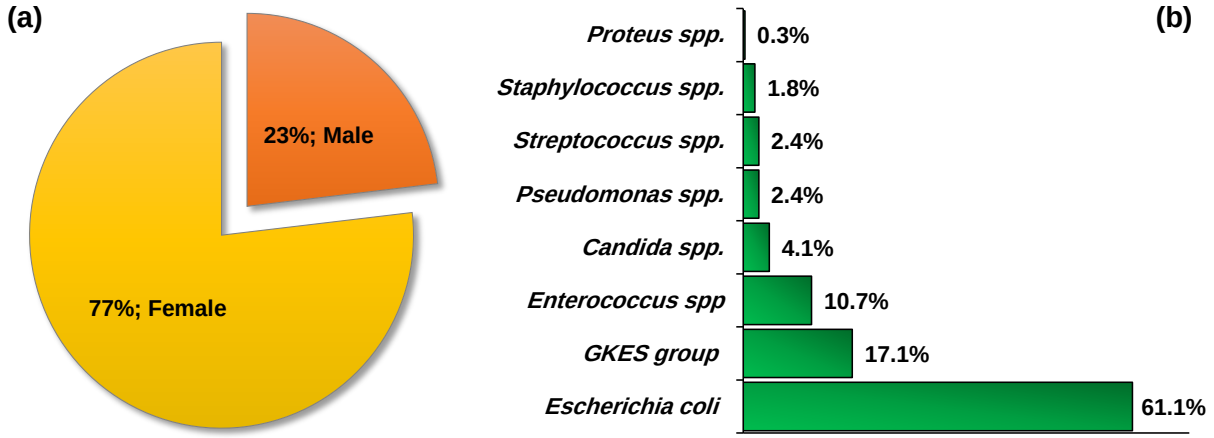

Fig. 2. Distribution by gender of positive UT infection cases (*a*); isolated species from the collected urine samples (*b*): GKES – *Klebsiella* spp., *Enterobacter* spp., and *Serratia* spp.

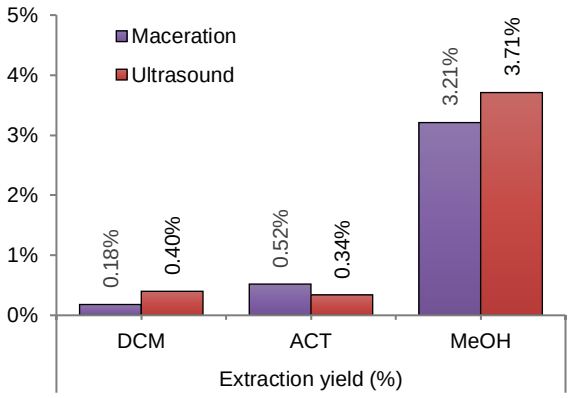

Fig. 3. Extraction yields across solvents and methods used expressed in dry weight percentage

Two different methods were used with three solvents to obtain extracts from the red algae. Our results revealed that the extraction yield of *A. armata* varied depending on the solvent and method used (Fig. 3). The highest yield was observed with ultrasonic assisted extraction when using methanol as a solvent at 3.71%.

Minimal inhibitory concentration (MIC) values of the extracts from *A. armata* were determined against eleven *E. coli* species using the microdilution method. The results revealed significant variations in antimicrobial activity among the extracts and across bacterial species. Table 3 reports MIC values for three extracts DCM (dichloromethane), ACT (acetone), and MeOH (methanol) obtained via maceration and ultrasound-assisted extraction (UAE) against 11 *E. coli* strains.

The methanol extract via the UAE method consistently demonstrated the strongest antibacterial effect, with a MIC range from 118.8 to 123.13 µg/mL for all strains. This extract was significantly more effective than any other extracts, showing low variability in its inhibition power, which underscores its reliability. MeOH -maceration, this method also showed strong activity, with a MIC between 156.91 and 158.51 µg/mL for 10 strains. Only *E. coli* 6158 showed reduced sensitivity (MIC = 317.15 µg/mL), indicating a resistance in that strain.

The MIC values for the ACT maceration method range from 459.17 to 470.83 µg/mL, for all strains, reflecting moderate activity, while those for UAE range from 1,009 to 1,016 µg/mL, except *E. coli* 19251 (505 µg/mL) and 6319 (510 µg/mL), suggesting variability in efficacy. It is observed that the MIC values for UAE are generally higher, which may indicate a different extraction efficiency for active compounds between the two methods.

Table 3
Minimal inhibitory concentration (µg/mL) of the extracts across *E. coli* strains

Bacterial strains	DCM extract		ACT extract		MeOH extract		Gentamicin
	maceration	UAE	maceration	UAE	maceration	UAE	
E. coli 19251	681.5 ± 18.6	437.5 ± 10.9	470.8 ± 8.8	505.0 ± 5.0	156.9 ± 5.0	120.8 ± 5.0	>25
E. coli 6319	698.1 ± 10.3	442.5 ± 15.2	462.5 ± 12.5	510.0 ± 5.0	157.3 ± 6.0	118.8 ± 9.2	3.90 ± 0.01
E. coli 6577	1371.5 ± 18.7	868.3 ± 20.2	459.2 ± 3.8	1010.0 ± 5.0	157.9 ± 6.6	120.1 ± 9.0	3.90 ± 0.01
E. coli 21450	1375.1 ± 22.0	871.7 ± 16.1	465.2 ± 4.2	1009.0 ± 1.0	156.2 ± 4.0	122.1 ± 7.1	3.90 ± 0.01
E. coli 21449	1371.5 ± 12.3	865.0 ± 15.0	464.2 ± 10.1	1016.0 ± 12.2	156.9 ± 5.0	119.1 ± 7.6	3.90 ± 0.01
E. coli 5939	690.7 ± 10.1	444.2 ± 14.2	463.5 ± 6.1	1013.0 ± 6.1	157.9 ± 6.6	121.5 ± 10.0	3.90 ± 0.01
E. coli 1706	1389.5 ± 9.1	861.7 ± 10.4	470.8 ± 8.8	1013.7 ± 7.2	158.2 ± 7.1	123.1 ± 8.7	3.90 ± 0.01
E. coli 1680	1371.5 ± 18.7	865.0 ± 10.0	462.8 ± 10.0	1014.3 ± 7.5	158.2 ± 7.1	120.1 ± 14.0	3.90 ± 0.01
E. coli 1703	684.1 ± 12.2	863.0 ± 9.2	463.5 ± 13.0	1013.0 ± 5.2	158.9 ± 8.2	123.1 ± 6.8	3.90 ± 0.01
E. coli 6158	1378.1 ± 15.9	863.3 ± 12.6	923.3 ± 7.6	1012.0 ± 3.5	317.2 ± 10.4	119.8 ± 6.6	3.90 ± 0.01
E. coli 6112	684.7 ± 12.7	861.7 ± 10.4	465.2 ± 13.7	1011.7 ± 2.9	157.6 ± 7.1	120.3 ± 5.0	3.90 ± 0.01

Table 3 shows that with the DCM maceration method, the MICs values range from 681.46 to 1,389.46 µg/mL, for all strains. *E. coli* 19251, *E. coli* 6319, *E. coli* 5939, *E. coli* 1703 and *E. coli* 6112 showed moderate sensitivity compared to other strains. The extract by UAE method improved DCM's performance slightly, with MICs between 437.5 µg/mL and 871.67 µg/mL, but still underperformed compared to MeOH.

Table 4 presents the antibiotic susceptibility profiles of 11 *E. coli* strains isolated from UTI against seven antibiotics: amoxicillin (AMC), cefotaxime (CTX), cephalothin (KF), ciprofloxacin (CIP), gentamicin (CN), cotrimoxazole (SXT), and cefoxitin (FOX). All strains were resistant to amoxicillin (AMC), showing a consistent resistance pattern. In contrast, cefotaxime (CTX) was effective against all strains, with universal sensitivity observed. For cephalothin (KF) and ciprofloxacin (CIP), variability was noted: *E. coli* 19251 was resistant to both, while most other strains remained sensitive. Gentamicin (CN) and cotrimoxazole (SXT) showed similar trends, with resistance observed in only a few strains (e.g., CN and SXT resistance in *E. coli* 19251, 1706, and 6158). Cefoxitin (FOX) was largely effective, with only *E. coli* 19251 showing resistance. Overall, the strains exhibited multidrug resistance, particularly *E. coli* 19251, which was resistant to all tested antibiotics. The remaining strains were generally sensitive to five or more antibiotics, indicating variable but not extreme resistance patterns.

Table 4
Antibiogram of *E. coli* species (11 isolated from UTI)

Bacterial strains	Antibiotics						
	Amoxicillin	Cefotaxime	Cephalothin	Ciprofloxacin	Gentamicin	Cotrimoxazole	Cefoxitin
E. coli 19251	R	S	R	R	R	R	R
E. coli 6319	R	S	S	R	S	S	S
E. coli 6577	R	S	S	S	S	S	S
E. coli 21450	R	S	S	S	S	R	S
E. coli 21449	R	S	S	S	S	S	S
E. coli 5939	R	S	S	R	S	S	S
E. coli 1706	R	S	S	S	S	R	S
E. coli 1680	R	S	S	S	S	S	S
E. coli 1703	R	S	S	S	S	S	S
E. coli 6158	R	S	S	S	S	R	S
E. coli 6112	R	S	S	S	S	R	S

The algae extract results, particularly for methanol extracts via UAE, reveal a broader spectrum and more consistent antibacterial effect compared to traditional antibiotics. While many *E. coli* strains showed resistance to multiple antibiotics, they remained sensitive to the methanolic plant extracts, even at low concentrations. This suggests that plant-based compounds, especially when extracted effectively, could serve as valuable alternatives or complements to conventional antibiotics, especially against resistant bacterial strains. The LC-MS/MS method was used to identify the major secondary metabolites present in algae extract (*A. armata*). Phenolic compounds in the plant samples were characterized by analyzing their retention times, high-resolution mass data, and mass spectrometry fragmentation patterns. Quantification of the identified compounds was expressed as a percentage of the total peak area (Table 5).

MeOH extract (ultrasound method) is especially rich in kaempferol (11.66–36.52%), quercetin (3.07–13.02%), hesperetin (4.17–10.01%) and rutin (13.50–11.33%). MeOH Maceration extract has a very high percentage of 2-methoxybenzoic acid (46.84%).

Table 5
Phenolic compounds identified in MeOH and Acetone extracts from *A. armata* using LC-MS/MS

ID	Name	Molecular formula	Molecular weight	Ret. Time	Acetone maceration, % area	Acetone ultrasound, % area	MeOH maceration, % area	MeOH ultrasound, % area
1	2-Methoxybenzoic acid	$C_8H_8O_3$	152.15	0.762	8.25	6.33	46.84	3.62
2	4-Mythoxybenzoic acid	$C_8H_8O_3$	152.15	0.763	10.43	8.14	1.56	2.61
3	Coumaric acid	$C_9H_8O_3$	164.16	0.763	33.23	27.82	14.71	8.01
4	4-hydroxy coumarin	$C_{27}H_{30}O_{16}$	162.14	0.771	0.06	0.08	0.00	0.00
5	Thymol	$C_{10}H_{14}O$	150.22	0.763	0.61	0.71	0.00	0.22
6	Naringenin	$C_{15}H_{12}O_5$	272.25	10.213	1.16	1.22	0.51	1.71
7	Salicylic acid	$C_7H_6O_3$	138.12	10.218	0.13	0.00	0.00	0.00
8	Gallic acid	$C_4H_4O_4$	170.12	10.981	0.13	0.12	0.02	0.11
9	Chrysin	$C_{15}H_{10}O_4$	254.24	11.055	0.00	0.42	0.00	0.43
10	Kaempferol	$C_{15}H_{10}O_6$	286.24	11.483	22.61	25.30	11.66	36.52
11	Valinin	$C_8H_8O_3$	152.15	11.874	0.85	2.34	0.45	1.01
12	Quercetin	$C_{15}H_{10}O_7$	302.23	12.116	6.66	8.12	3.07	13.02
13	Kojic acid	$C_6H_6O_4$	142.11	12.657	0.88	1.15	0.31	2.09
14	Ferulic acid	$C_{10}H_{10}O_4$	194.18	14.218	3.03	3.25	1.44	4.90
15	Chlorogenic acid	$C_{16}H_{18}O_9$	354.31	14.936	0.00	0.06	0.00	0.00
16	Myricetin	$C_{15}H_{10}O_8$	318.23	16.558	0.00	0.19	0.00	0.00
17	Hesperetin	$C_{16}H_{14}O_6$	302.28	16.748	3.16	7.83	4.17	10.01
18	Beta carotene	$C_{40}H_{56}$	536.87	17.090	1.27	2.14	0.32	2.98
19	Rutin	$C_{27}H_{30}O_{16}$	610.50	18.361	6.79	3.44	13.50	11.33
20	Folic acid	$C_{19}H_{19}N_7O_6$	441.14	17.015	0.64	1.15	1.38	1.30
21	Cis-*p* coumaric acid	$C_9H_8O_3$	164.16	19.924	0.11	0.21	0.05	0.14

The most notable phenolic compounds detected in the acetone extract of both methods (maceration and ultrasound) were coumaric acid (27.82–33.23%), and kaempferol (22.61–25.30%) and 4-mythoxybenzoic acid (8.14–10.43%), whereas 2-methoxybenzoic acid, rutin, quercetin, ferulic acid and hesperetin were present in varying amounts, from 3.03% to 8.25%.

Both MeOH and acetone extracts contain multiple phenolic compounds, but the profile and relative amounts differ between the two solvents. the main phenolic acids present in the MeOH and acetone extracts include gallic acid, vanillic acid, syringic acid, p-hydroxybenzoic acid, caffeic acid and ferulic acid. Phenolic acids are known for their antibacterial effects. For example, gallic acid, caffeic acid, and ferulic acid can damage bacterial cell walls and disrupt their function. The MeOH extract shows strong antibacterial activity, which is likely due to the presence and concentration of these phenolic acids.

The antibacterial activity of the MeOH and acetone extracts from *A. armata* can be linked to the phenolic acids identified by LC-MS/MS, such as coumaric acid, kaempferol, and 2-methoxybenzoic Acid. These compounds are known to have antibacterial properties, and their presence in higher concentrations may explain the observed inhibition of bacterial growth.

Discussion

The prevalence rate of UTIs revealed in this study (23%) aligns with and slightly exceeds findings from other studies conducted in Algeria (Khelfaoui et al., 2020; Benmoumou et al., 2023), which refers to the similar conditions and environments in the study regions. Our study also found that the most frequent causative agents of UTIs are bacteria, particularly *E. coli* (61%). These findings are in agreement with studies previously conducted in other regions of Algeria (Adouane et al., 2024) and other countries (Guermazi-Toumi et al., 2018).

The distribution of UTIs does not appear to be influenced by gender, as the predominant species were isolated from both males and females. However, the higher levels of UTIs in females (26% of total female samples) can be attributed to anatomical and behavioral factors. Females have a short urethra, which facilitates bacterial movement into the urinary tract. Additionally, certain behaviors such as delayed urination, sexual activity and the use of diaphragms and spermicides can promote the colonization of coliform bacteria including in the periurethral area. The close proximity of the urethral meatus to the anus further increases the risk of bacterial transmission, particularly for coliform species (Benmoumou et al., 2023; Kara et al., 2024).

Similar results have been obtained in other surveys of UTI gender distribution (Ait-Mimoune et al., 2022) revealing that females were more affected with a sex ratio of 1.14 (Female/male). Our records differ from those recorded by Salem et al. (2018). where the distribution of infection rates was much greater in females (81%) than in males (18.6%).

In this study we evaluated the efficacy of three extraction solvents, using two methods (cold maceration and ultrasonic-assisted extraction UAE). Our findings revealed that methanol provided a higher chemical extraction yield with the methods used compared to acetone (ACT) and dichloromethane (DCM) which showed lower yields with both methods.

These results are consistent with previous studies on solvent-based extractions from marine algae. For example, Mellouk et al. (2017) investigated seven solvents for extracting bioactive compounds from the red algae *Asparagopsis taxiformis*. In their study, the methanolic extract demonstrated the second-highest extraction yield after the aqueous extract, further supporting methanol as an extraction solvent. Conversely the acetone procedure yielded the lowest extraction efficiency, exceeded only by petroleum ether (Mellouk et al., 2017). In another study, the extraction yields of four solvents dichloromethane, hexane, water and methanol from the red marine algae *A. taxiformis* were assessed. The results indicated that dichloromethane had the second-lowest extraction yield (1.9%), following hexane (0.5%) (Machado et al., 2016). These findings collectively highlight the influence of solvent polarity on extraction efficiency and underscore the importance of selecting appropriate solvents before the extraction procedure based on the desired outcomes (Bhadange et al., 2024).

A remarkable antibacterial activity of the methanolic extract has been noticed in this study. According to the microdilution results, MIC values of this extract showed the most potent activity across all tested strains. It has been also noted that all tested extracts had a broad spectre of activity against *E. coli* strains, which confirms results obtained of a literature study (Zainuddin et al., 2020) which investigated the antibacterial activities of the extracts from 26 species macroalgae prepared with dichloromethane, methanol and water against five pathogenic bacteria. The highest activities were obtained by the dichloromethane prepared extracts. The most active algal species was *A. armata* against all tested bacteria.

The methanolic extract of twenty three red marine algae including *A. armata* collected along the Atlantic coast of Morocco provided the highest antibacterial activity against bacterial pathogens, including *E. coli* (Oumaskour et al., 2019).

The antibacterial activity of *A. armata* extracts against *E. coli* was strongly influenced by both the extraction solvent and method. Methanol extracts, particularly those obtained by ultrasound-assisted extraction (UAE), demonstrated the lowest MIC values (as low as 119 µg/mL), indicating potent antibacterial effects. This high activity correlates with the elevated levels of flavonoids such as kaempferol, quercetin, rutin, and hesperetin, as well as phenolic acids like ferulic acid, identified in these extracts by LC-MS/MS. These compounds are known for their ability to disrupt bacterial cell membranes and inhibit microbial growth. In contrast, acetone and DCM extracts, which contained lower amounts of these active phenolics, exhibited higher MIC values and thus weaker antibacterial effects. These results suggest that the phenolic composition, particularly the abundance of flavonoids and phenolic acids, plays a key role in the antibacterial efficacy of *A. armata* extracts.

Conclusion

This study underscores the significant burden of UTIs in Algeria, driven by *E. coli* and fuelled by antibiotic resistance. The evaluation of *A. armata* extracts reveals that methanol-derived extracts are highly effective against multidrug-resistant *E. coli*, with MIC values comparable to or better than other solvents. These findings address critical gaps in regional research by providing the first assessment of *A. armata*'s activity against clinically isolated UTI pathogens in Algeria. The superior performance of methanol extracts highlights solvent selection as a key factor in optimizing bioactive compound recovery, while the broad-spectrum activity of all extracts underscores their therapeutic potential. This work contributes to global efforts to combat antimicrobial resistance by exploring marine-derived alternatives, offering a sustainable path forward for UTI management. Future studies should focus on isolating active metabolites, assessing clinical safety, and evaluating scalability for potential drug development.

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