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RESEARCH ARTICLE

# Exploring the chemistry of coastal plant *Achillea maritima*: Clues to its antioxidant potential

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**Abstract**

In this study, we investigated the potential applications of *Achillea maritima* by analyzing its chemical composition and biological activities. Fresh above ground parts of *A. maritima* were collected and processed to obtain an extract. Phytochemical analysis revealed high levels of total phenolic content (234.44 ± 6.05 mg GAE/g extract DW) and total flavonoid content (74.14 ± 4.59 mg QE/g extract DW). The antioxidant potential was assessed using DPPH free radical scavenging assay, with an $IC_{50}$ value of 0.32 ± 0.01 mg/mL, and iron-chelating ability, with an $IC_{50}$ value of 5.64 ± 0.33 mg/mL. Gas chromatography-mass spectrometry (GC-MS) analysis identified polyphenolic compounds and flavonoids as predominant constituents, with bis (methyl sulfonyl) methane being the major contributor to antioxidant properties. Additionally, three trace compounds were discovered for the first time in plants. Overall, *A. maritima* extract exhibited significant antioxidant potential, supported by its rich phenolic and flavonoid content, suggesting its potential value in pharmaceutical and other industries. These findings provide a basis for further exploration of *A. maritima*'s diverse applications.

**KEYWORDS**

*Achillea maritima*, antimicrobial activity, antioxidant capacity, Asteraceae, phenolic content

## 1 | INTRODUCTION

Antioxidants, commonly utilized in food to prevent or delay oxidation, enhance food stability, and extend storage time, may be sourced through natural or synthetic means. Recently, a trend has emerged to limit synthetic antioxidants in the food industry because of their potential toxic impact on consumer health because of overuse or misuse.[1] Some studies have demonstrated that commonly utilized synthetic antioxidants may gather within the liver, leading to damage and potentially promoting the development of cancer. For this reason, natural plant-derived ingredients are used in the food industry as alternative additives to improve food safety and stability.[2,3]

Reactive oxygen and nitrogen species in cells can have excess oxidant capacity, causing various problems such as oxidative stress, tissue damage, DNA damage, lipid peroxidation, and protein oxidation.[4] Salt-tolerant plants develop physiological and metabolic adaptations to protect themselves from adverse external factors such as ion toxicity, osmotic shock, nutrient imbalance, and oxidative damage.[5] These adaptations include increased root and shoot biomass, exclusion of toxic ions, and preservation of active nutrients. Under salt stress, excessive production of free oxygen radicals harms nucleic acids, proteins, lipids, other macromolecules, and intracellular membranes. Many plants have adapted to overcome the oxidative stress caused by salt by developing an effective antioxidant system.[5–8]

The name of the *Otanthus maritimus* (L.) Hoffmanns. & Link species, known by different names after it was first described in 1753, became the most frequently used in 1853, and this name was used for the species until 2005. In 2005, the genus *Otanthus* was merged with the genus *Achillea*, which led to the acceptance of the name *Achillea maritima* (L.) Ehrend. & Y. P. Guo for the species.[9,10] The *Achil-*

**FIGURE 1** The appearance of *A. maritima* in nature.

*lea* genus holds economic and medicinal importance within the Asteraceae family, consisting of over 100 species distributed across the Middle East, East and West Asia, North America, Europe, New Zealand, and Australia.[11] *A. maritima* species has white gray, densely cottony leaves and stems. This perennial species grows along the coastal dunes from Southern and Western Europe towards Southeast Ireland (Figure 1). *A. maritima* has been used in traditional medicine for a variety of ailments, including dysentery, bladder inflammation, asthmatic bronchitis, and dental pain.[12,13] Extracts obtained from the above-ground parts of *A. maritima* have been found to contain various components, including flavonoids, sesquiterpene lactones, and sesamin-like compounds.[14–16] Additionally, major components among the volatile compounds include artemisyl acetate, santolina triene, and camphor.[17]

Despite the known importance of *A. maritima* in traditional medicine, there is insufficient information regarding its antioxidant and antimicrobial activities. Therefore, this study aims to comprehensively investigate the antioxidant and antimicrobial potential of *A. maritima*, determine its total phenolic and flavonoid content, and characterize its phytochemical profile through GC-MS analysis (See Figure 2).

## 2 | MATERIALS AND METHODS

### 2.1 | Plant material

*A. maritima* samples were collected from the coastal dunes of the Hurriyet neighborhood, Costal area (Çarşamba/SAMSUN) (GPS: 41o15'38.91' N 36o31'03.40' E) on October 10, 2021. The collected plant samples were dried in a 50 °C oven for 2 days. Dr Alper DURMAZ identified the collected field samples, and the identified specimens are preserved in the Ondokuz Mayıs University Herbarium (OMUB) with the accession number 8911.

### 2.2 | Extraction

The dried plant samples were macerated using a biomass/solvent ratio of 1:4 (w/v) with ethanol. The maceration process lasted 2 days at room temperature. The resulting ethanol extracts were filtered using filter paper. The filtered extracts were then dried with a rotary evaporator under reduced pressure at 40 °C to remove the solvent. The obtained solid extracts were stored at a temperature of 4 °C until they were analyzed.[18]

### 2.3 | Total phenolic content (TPC) quantitation

This study determined total phenolics by a modified Folin and Ciocalteu method.[19] Following an incubation period of 3 min, 2% sodium carbonate was introduced to the reaction solution. The absorbance was read at 760 nm wavelength by a microplate reader (Thermo Scientific Varioskan Flash) after 1 hour incubation in the dark. The total phenolic content values are expressed as mg gallic acid equivalent (GAE)/g extract DW.

### 2.4 | Total flavonoid content (TFC) quantitation

In this study, total flavonoids were determined by a modified $AlCl_3$ method.[20] The extract (1 mg/mL) was mixed with an equal amount of a 2% ethanol solution of $AlCl_3.6H_2O$. After incubation for 10 min, the absorbance was measured at 367 nm with a microplate reader (Thermo Scientific Varioskan Flash). The total flavonoid content values are expressed as mg quercetin equivalent (QE)/g extract DW.

### 2.5 | Determination of radical scavenging activity

The extracts' ability to scavenge free radicals was measured using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay comparing the $IC_{50}$ value of the synthetic antioxidant butylated hydroxytoluene (BHT).[21] Varying extract concentrations were mixed with a DPPH radical (0.1 mM) ethanol solution in a 96-well microplate. After a 30-min incubation period without light, the absorbance was quantified using a microplate reader at 517 nm relative to a blank sample (Thermo Scientific Varioskan Flash). The DPPH radical scavenging activity of the extract was calculated as a percentage using the equation provided:

$$\text{DPPH radical scavenging activity } (\%) = \left[\frac{(\text{Abs control} - \text{Abssample})}{\text{Abscontrol}}\right] \times 100$$

An extract concentration curve versus percentage inhibition was made to determine the extract concentration to

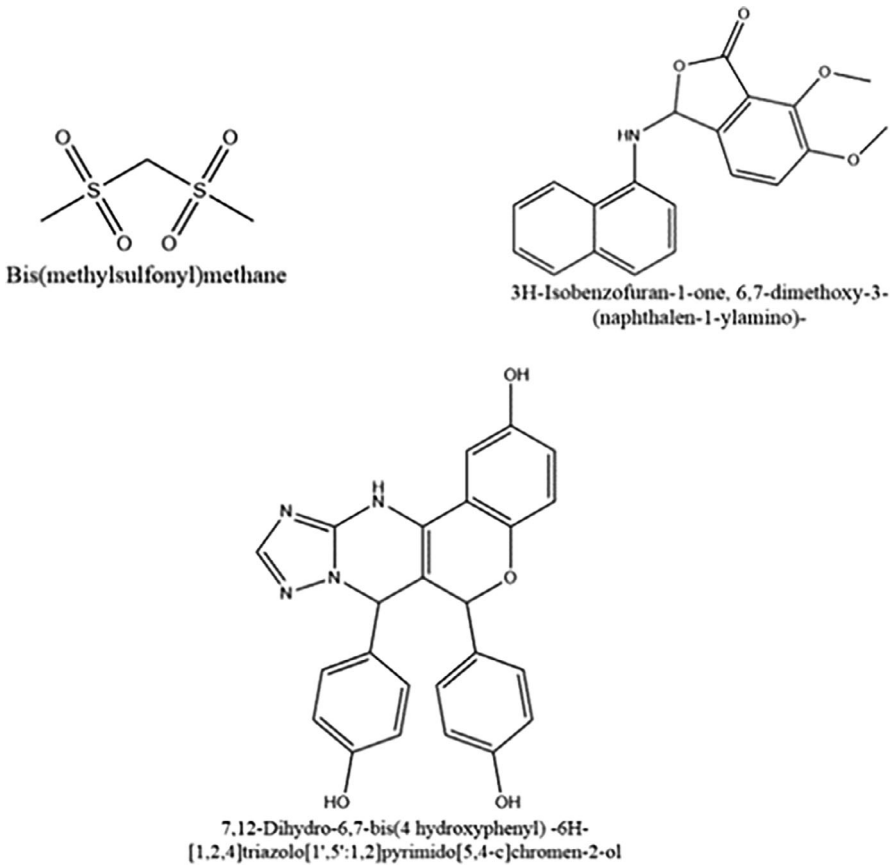


**FIGURE 2** Major compounds identified from *A. maritima* GC-MS analysis results.

cause the starting DPPH concentration to decrease by 50%. The value calculated by linear regression analysis is referred to as $IC_{50}$. The lower $IC_{50}$ value indicates higher antioxidant activity.

## 2.6 | Determination of the chelating ability of ferrous ions

Different extract concentrations were incubated with 2 mM $FeCl_2$ for 5 min. Afterwards, a 5 mM ferrozine solution was added and left for 10 min. After incubation, the absorbance was measured at 562 nm using a microplate reader (Thermo Scientific Varioskan Flash) with a blank as a reference. Ethylenediaminetetraacetic acid (EDTA) was used as a reference standard. The following equation was used to determine the percentage of ferrous ion chelating potential of the sample:

$$\text{Ferrous ion chelating ability } (\%) = \left[\frac{(\text{Abs control} - \text{Abssample})}{\text{Abscontrol}}\right] \times 100,$$

where $IC_{50}$ value was determined by a linear regression curve representing concentration of extracts chelating 50% of iron ion.[22]

## 2.7 | Antimicrobial activity

Gram-positive strains *Staphylococcus aureus* subsp. *aureus* ATCC 25923, *Enterococcus faecalis* ATCC 51299 (Drug-resistant *Enterococcus faecalis*-DRE), *Staphylococcus aureus* subsp. *aureus* ATCC 43300 (Methicillin-resistant *Staphylococcus aureus*-MRSA), *Bacillus cereus* ATCC 14579, Gram-negative strains *Klebsiella pneumoniae* subsp. *pneumoniae* ATCC 13883, *Escherichia coli* ATCC 25922, *Proteus vulgaris* RSKK 96029, and yeast strains *Candida albicans* ATCC 10231 and *Candida krusei* ATCC 6258 were chosen for the antimicrobial activity of plant extract. The bacterial and yeast cultures were grown on Mueller Hinton Broth and Sabouraud Dextrose Broth at 37 and 30 °C, respectively. Cultured cells were suspended in 10 mL physiological saline, and the optical density read was compared to 0.5 McFarland standard ($1.5\times10^8$ colony-forming unit/mL).

The broth microdilution assay following CLSI reference methods M07-A9 and M27-A3 was used to determine the plant extract's minimal inhibitory concentration (MIC) against bacteria and yeasts (CLSI, 2012, CLSI, 2008). Standard antibacterial agents' ampicillin, chloramphenicol, and antifungal ketoconazole were positive controls. Minimal bactericidal concentration (MBC) and minimal fungicidal concentration (MFC) values were evaluated by subculturing from non-turbid wells and spot inoculating onto an appropriate growth medium.

**TABLE 1** DPPH radical scavenging and iron chelating activities of *A. maritima* ethanol extracts ($IC_{50}$ mg/mL) ± SD) and total phenolic and flavonoid contents ± SD* values.

| | DPPH ($IC_{50}$ mg/mL) | Iron chelating ($IC_{50}$ mg/mL) | Total phenolic compound (mg GAE/g extract DW) | Total flavonoid compound (mg QE/g extract DW) |
|---|---|---|---|---|
| *A. maritima* ethanol extracts | 0.32 ± 0.01 | 5.64 ± 0.33 | 234.44 ± 6.05 | 74.14 ± 4.59 |
| BHT | 0.23 ± 0.00 | – | – | – |
| EDTA | – | 5.30 ± 4.44 | – | – |

## 2.8 | Gas chromatography-mass spectrometry analysis

The gas chromatography-mass spectrometry (GC-MS) instrument equipped with the following specifications was used to perform the GC-MS analysis. Instrument: Trace 1300 Gas Chromatographs, coupled with a Thermo mass spectrometer detector (ISQ 7000 MS, TriPlus RSH Autosampler ISQ 7000 MS, TriPlus RSH Autosampler). The analysis was conducted utilising helium as the carrier gas with a flow rate of 1.0 mL/min and a split ratio of 1:10. The temperature program employed followed an initial temperature of 60 °C for 1 min, followed by a gradual increase at a rate of 4.0 °C $min^{-1}$ until reaching 240 °C, which was then held for 1 min. The injector and detector temperatures were both set at 210 °C. 1 µL of diluted samples (1:10 in hexane, v/v) were injected for analysis. Mass spectra were acquired through electron ionization (EI) at 70 eV, using a spectral range of m/z 40–450. The Wiley spectral library collection and NSIT library database identified the chemical constituents.[18]

## 3 | RESULTS AND DISCUSSION

Antioxidant activity relates to antioxidants such as phenolic compounds and flavonoids, which act as effective scavengers of reactive oxygen species (Table 1). The plant extract showed potent antioxidant activity as determined by DPPH assay with an $IC_{50}$ value of 0.32 ± 0.01 mg/mL. However, the $IC_{50}$ value of butylated hydroxytoluene (BHT), a synthetic antioxidant molecule, was 0.23 ± 0.00 mg/mL. Iron ions ($Fe^{2+}$) can cause lipid peroxidation and food spoilage. Therefore, chelating iron ions can reveal a substance's antioxidant capacity. The iron chelating ability of *A. maritima* was determined to have an $IC_{50}$ value of 5.64 ± 0.33 mg/mL, comparable to the control group with EDTA. This result indicates its high antioxidant capacity. Additionally, the total phenolic content was determined to be 234.44 ± 6.05 mg GAE/g extract DW, while the total flavonoid content was measured at 74.14 ± 4.59 mg QE/g extract DW.

At concentrations, the plant extract showed no antimicrobial activity on *E. coli*, *S. aureus*, *Bacillus cereus*, and DRE. It was determined that the extract showed a better effect than ampicillin, which is the positive control, according to the MIC and MBC values on *K. pneumoniae* ATCC 13883. It was also found that the MIC value of the extract on *P. vulgaris* RSKK 96029 was lower than ampicillin and chloramphenicol, and the MIC value on *C. albicans* ATCC 10231 was lower than ketoconazole (Table 2).

**TABLE 2** Antimicrobial activity of the *A. maritima* extract and positive controls (mg/mL).

| Microorganisms | | *A. maritima* | Amp[a] | C[b] | Keto[c] |
|---|---|---|---|---|---|
| ***E. coli* ATCC 25922** | MIC[d] | >50 | >125 | 125 | NS |
| | MBC[e] | >50 | >125 | >125 | NS |
| ***S. aureus* ATCC 25923 +** | MIC | >50 | 62.5 | 125 | NS |
| | MBC | >50 | 62.5 | >125 | NS |
| ***K. pneumoniae* ATCC 13883** | MIC | 25 | 125 | 15.63 | NS |
| | MBC | 50 | 125 | 15.63 | NS |
| ***P. vulgaris* RSKK 96029** | MIC | 50 | >125 | 125 | NS |
| | MBC | >50 | >125 | >125 | NS |
| ***Bacillus cereus* ATCC 14579+** | MIC | >50 | 31.25 | 125 | NS |
| | MBC | >50 | >125 | 125 | NS |
| **MRSA ATCC 43300+** | MIC | 50 | 7.81 | 15.63 | NS |
| | MBC | >50 | 15.63 | 31.25 | NS |
| **DRE ATCC 51299** | MIC | >50 | 15.63 | 7.81 | NS |
| | MBC | >50 | 31.25 | 15.63 | NS |
| ***C. albicans* ATCC 10231** | MIC | 25 | NS | NS | 31.25 |
| | MFC[f] | >50 | NS | NS | 62.5 |
| ***C. krusei* ATCC 6258** | MIC | 50 | NS | NS | <0.98 |
| | MFC | >50 | NS | NS | 15.63 |

[a]Ampicillin.
[b]Chloramphenicol.
[c]Ketoconazole.
[d]Minimal inhibitory concentration.
[e]Minimal bactericidal concentration.
[f]Minimal fungicidal concentration.

Several bioactive compounds have been detected in the ethanol extract of the above ground parts of *A. maritima*. The retention time (RT), molecular formula, molecular weight (MW), and concentration (% peak area) of 10 bioactive phytochemical compounds in the extract are shown in Table 3. According to the results, the main components were identified as bis(methylsulfonyl)methane (77.08%), 3H-isobenzofuran-1-one, 6,7-dimethoxy-3-(naphthalen-1-ylamino)- (3.88%), and 7,12-dihydro-6,7-bis(4-hydroxyphenyl)-6H-[1,2,4]triazolo[1′,5′:1,2]pyrimido[5,4-c]chromen-2-ol (2.47%). The major compounds obtained from GC-MS analysis are shown in Figure 1.

**TABLE 3** GC-MS analysis of *A. maritima* ethanol extract.

| No | RT (min) | Name of the compound | Molecular formula | Molecular weight | Area % |
|---|---|---|---|---|---|
| 1 | 19.36 | Bis(methylsulfonyl)methane | $C_3H_8O_4S_2$ | 172.20 | 77.08 |
| 2 | 19.75 | 1H-azepine-1-carboxylic acid, 3-methyl-, methyl ester | $C_9H_{11}NO_2$ | 165.19 | 1.24 |
| 3 | 42.08 | 3H-isobenzofuran-1-one, 6,7-dimethoxy-3-(naphthalene-1-ylamino)- | $C_{13}H_{24}O_6$ | 276.33 | 3.88 |
| 4 | 45.13 | Propyl gallate | $C_{10}H_{12}O_5$ | 212.20 | 1.62 |
| 5 | 46.96 | 3,6-dimethoxy-2,5-dinitro benzaldehyde oxime | $C_9H_9N_3O_7$ | 271.18 | 0.96 |
| 6 | 47.81 | 7,12-dihydro-6,7-bis (4 hydroxyphenyl) -6H- [1,2,4] triazolo[1′,5′:1,2]pyrimido[5,4-c]chromen-2-ol | $C_{24}H_{18}N_4O_4$ | 426.00 | 2.47 |
| 7 | 49.42 | *N*-(2,5-dimethyl-phenyl)-2-(pyridine-2-ylamino)-2-thioxo-acetamide | $C_{15}H_{15}N_3OS$ | 285.00 | 1.25 |
| 8 | 49.77 | Pregn-4-ene-3,20-dione,11,21-dihydroxy-, (11\|A)- | $C_{21}H_{30}O_4$ | 346.50 | 1.62 |
| 9 | 49.85 | N-(4-bromo-2-nıtro-phenyl)-N-(2-hydroxy-3-nethoxy-benzylıdene-hydrazınocarbonylmethyl)-benzenesulfonamıde | $C_{22}H_{19}BrN_4O_7S$ | 562.00 | 1.87 |
| 10 | 50.79 | 2,5-dimethoxyamphetamine | $C_{11}H_{17}NO_2$ | 195.26 | 1.44 |

The term "antioxidant" refers to a chemical compound that prevents oxygen consumption; however, antioxidants perform various functions, including radical scavenging, electron donation, hydrogen donation, peroxide decomposition, enzyme inhibition, synergistic effects, and metal chelation.[23] Free radicals and oxidants play a dual role in the body, which can be harmful or beneficial. These compounds can arise from normal cellular metabolism and external factors such as environmental pollution, smoking, radiation, and pharmaceuticals. Excessive accumulation of free radicals leads to oxidative stress, which can contribute to a range of health issues, including autoimmune disorders, cancer, aging, cardiovascular diseases, and neurodegenerative diseases. Nevertheless, the body naturally combats oxidative stress by producing or obtaining endogenous antioxidants from food and supplements.[24] The total phenolic content, flavonoids, and antioxidant activity tests of the ethanolic extract of *A. maritima* provide evidence of their medicinal properties. The total phenolic content, flavonoid profile, and antioxidant activity tests of the ethanol extract of *A. maritima* provide significant evidence of its medicinal properties. The plant exhibits notable antioxidant activity, and it has been observed that the extract is rich in flavonoids and phenolic compounds.

In the study by Elkiran et al., essential oils obtained from the flowers and leaves of *A. maritima* showed low activity (8–9 mm) against Gram-negative bacteria and no effect against Gram-positive bacteria. However, they exhibited high activity against *C. krusei* and *C. parapsilosis* (20–22 mm). According to the MIC test results, the essential oil was effective against *C. krusei* and *C. parapsilosis* at a concentration of 50 µL/mL. The antioxidant activity of the essential oil was determined to have an $IC_{50}$ value of 31.9 µL/mL. The volatile oil isolated from *A. maritima* was rich in yomogi alcohol, camphor, artemisia alcohol, and 2-methyl-1-butanol.[25] Our study determined that the ethanol extract obtained from the aerial parts of *A. maritima* showed no antimicrobial activity against Gram-negative bacteria (*E. coli* and DRE) and Gram-positive bacteria (*S. aureus* and *Bacillus cereus*).

In contrast, Elkiran et al. reported that the essential oils obtained from the flowers and leaves of *A. maritima* exhibited low activity against Gram-negative bacteria and no effect against Gram-positive bacteria. Furthermore, it was found that the ethanol extract from the aerial parts of *A. maritima* showed no antimicrobial activity against *C. krusei*. In contrast, the essential oils in Elkiran et al.'s study demonstrated high antimicrobial activity. Additionally, Elkiran et al. found that the antioxidant activity of *A. maritima's* essential oils was higher than that of our study.

In the study by Bilgi et al., the phenolic content of ethyl acetate extract from the above ground parts of *A. maritima* was reported as 954.94 ± 38.36 mg GAE/g extract DW, hexane extract as 688.24 ± 10.25 mg GAE/g extract DW, water extract as 507.46 ± 4.19 mg GAE/g extract DW, ethanol extract as 309.35 ± 16.14 mg GAE/g extract DW, chloroform extract as 334.86 ± 4.04 mg GAE/g extract DW, and butanol extract as 103.51 ± 8.71 mg GAE/g extract DW. Additionally, the ethanol extract showed the highest DPPH radical scavenging activity at 601.41 ± 8.34 mg Trolox/g, followed by hexane extract at 465.82 ± 17.18 mg Trolox/g, chloroform extract at 349.11 ± 1.63 mg Trolox/g, ethyl acetate extract at 604.15 ± 11.57 mg Trolox/g, butanol extract at 541.49 ± 18.49 mg Trolox/g, and water extract at 461.57 ± 0.68 mg Trolox/g.[26] In the study by Bilgi et al., the phenolic contents of ethyl acetate, hexane, water, ethanol, and chloroform extracts obtained from the aerial parts of *A. maritima* were higher than ours. However, the phenolic content of the butanol extract was lower in our research. Additionally, both studies indicated that the extracts from the aerial parts of *A. maritima* exhibit significant antioxidant potential.

In the study by Chekroud et al., the total phenolic content of the methanol extract from the above ground parts

of *A. maritima* was reported as 27.75 mg GAE/g extract DW, and the total flavonoid content was reported as 11.33 mg QE/g extract DW. The study also observed that the essential oil of *A. maritima* exhibited a significant inhibition zone of 9 ± 0.27 mm against *S. aureus*. The essential oil showed inhibition zones of 6 ± 0.43 mm against *E. coli* (pus), 6 ± 0.5 mm against *E. coli* (urine), 6 ± 0.3 mm against *E. coli* ATCC 25922, 6 ± 0.1 mm against *S. aureus* ATCC 29213, 7 ± 0.5 mm against *K. pneumoniae*, 6 ± 0.35 mm against *P. aeruginosa*, and 6 ± 0.35 mm against *C. albicans* ATCC 10231. The control disc also showed an inhibition zone of 6 ± 0.5 mm. These findings indicate that the essential oil of *A. maritima* possesses selective antimicrobial activity, particularly effective against *S. aureus*.[27] Our study determined that the ethanol extract obtained from the aerial parts of *A. maritima* exhibited a higher phenolic and flavonoid content than the methanol extract reported by Chekroud et al. While Chekroud et al. indicated that the essential oil of *A. maritima* demonstrated antimicrobial activity against *E. coli* (pus), *E. coli* (urine), *E. coli, S. aureus, K. pneumoniae*, *P. aeruginosa*, and *C. albicans*, our findings showed that the ethanol extract from the above-ground parts of A. *maritima* did not exhibit any antimicrobial activity against *E. coli*. However, it was found to possess good antimicrobial activity against *K. pneumoniae*.

In the study by Kaloteraki et al., the total phenolic content of *A. maritima* water extract was reported as 1.33 ± 0.38 mg GAE/g, and the total antioxidant content was reported as 0.47 ± 0.06 mmol $Fe^{2+}$/L.[28] In the study by Kaloteraki et al., the total phenolic content of the water extract of *A. maritima* was lower than the ethanol extract obtained from the aerial parts of *A. maritima* in our study. Both studies demonstrated that the antioxidant content exhibited good activity.

In the study by Mazoir, the ethyl acetate and butanol extracts obtained from the above-ground parts of *A. maritima* they have exhibited significant antioxidant activity, ranging from 88.29 to 89.72% at concentrations of 0.12 and 0.06 mg/mL, respectively. The ethyl acetate extract demonstrated a ferrous ion chelation activity of 83.1%, significantly higher than the EDTA positive control (100%). Additionally, the chelation activities of the dichloromethane and aqueous extracts for $Fe^{2+}$ were reported to be 48.88 and 45.81%, respectively. In contrast, the chelation activities of the hexane and butanol extracts were lower, at 9.5 and 11.3%, respectively.[29] In our study, the antioxidant activity of the ethanol extract obtained from the above-ground parts of *A. maritima* demonstrated quite good activity compared to the standards. In the study by Mazoir, it was reported that the ethyl acetate and butanol extracts obtained from the above ground parts of *A. maritima* exhibited significant antioxidant activity.

Additionally, regarding iron chelating activity, it was determined that the ethanol extract showed similarly good activity compared to the standards. In Mazoir's study, the ethyl acetate extract of *A. maritima* exhibited high iron ion chelation activity. In contrast, the dichloromethane, aqueous, hexane, and butanol extracts showed lower iron chelation activity than our study.

In the study by Aytar et al., a sustainable synthesis of carbon quantum dots (CQDs) derived from *A. maritima* (AM) extract was developed. In this work, AI-based characterization integration was implemented to investigate the antioxidant properties and adsorption performance of AM-CQDs against methylene blue. By incorporating environmental factors into the optimization, control over the synthesis of AM-CQDs was achieved. The antioxidant capacity of AM-CQDs was determined with values as follows: CUPRAC assay: 35.76 ± 0.52, ABTS/HRP assay: 21.95 ± 0.31, DPPH assay: 6.13 ± 0.08, and Folin assay: 40.26 ± 0.57. Additionally, the adsorption efficiency was evaluated by measuring their capacity to remove MB, resulting in a %uptake 64.82. The findings highlight AM-CQDs' potential as effective antioxidants and adsorbents for environmental remediation and biomedical applications.[30]

AM-CQDs demonstrated high antioxidant activity through various methods, achieving a value of 40.26 ± 0.57 in the Folin assay. In contrast, the *A. maritima* ethanol extract exhibited strong antioxidant properties with an $IC_{50}$ value of 0.32 mg/mL in the DPPH assay.

This study identified Bis (methyl sulfonyl) methane in *A. maritima* through GC-MS analysis. It is an organic compound derived from the oxidation of dimethyl sulfoxide (DMSO), a methyl compound containing a sulfone group. Bis (methyl sulfonyl) methane is commonly used as a sulfur source and can also be consumed as a supplement. It has been suggested that MSM possesses anti-inflammatory and analgesic properties[31] and can support joint health, alleviate symptoms of osteoarthritis, and promote muscle and connective tissue recovery.[32] Bis (methyl sulfonyl) methane, newly identified in *A. maritima*, is present in a high proportion (approximately 77%). It plays a significant role in the antioxidant activity of the ethanol extract. Additionally, 3*H*-Isobenzofuran-1-one, 6,7-dimethoxy-3-(naphthalen-1-ylamino)- and 7,12-dihydro-6,7-bis(4 hydroxyphenyl)-6H-[1,2,4]triazolo[1′,5′:1,2]pyrimido[5,4-c]chromen-2-ol, which are present in trace amounts compared to Bis(methyl sulfonyl)methane, have been identified for the first time in plants in the literature.

## 4 | CONCLUSIONS

These results highlight the potential of *A. maritima* as a natural source of antioxidants. The presence of phenolic compounds and flavonoids in the ethanol extract contributes to its potent antioxidant properties. Further research and exploration of *A. maritima* and its bioactive constituents can lead to the development of novel antioxidant-based therapeutic interventions and functional food products.

### CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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