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EVALUATION OF CYTOTOXIC AND ANTIMICROBIAL ACTIVITIES OF METHANOLIC EXTRACTS FROM *Cystoseira foeniculacea* AND *Sargassum vulgare*

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Abstract. This study investigates the cytotoxic and antimicrobial activities of methanolic extracts derived from *Cystoseira foeniculacea* and *Sargassum vulgare*, two edible brown algae collected from the Mediterranean Sea. Cytotoxic effects were assessed on HepG2, MCF-7 and MDA-MB-231 cell lines, while antimicrobial activity was evaluated against clinically relevant bacteria and yeast strains. *Cystoseira foeniculacea* exhibited potent antiproliferative effects, particularly on HepG2 (IC_{50}: 35.25 µg/mL) and MCF-7 (IC_{50}: 105.5 µg/mL) cells. In contrast, *Sargassum vulgare* displayed limited cytotoxicity but demonstrated selective antimicrobial activity against *Enterococcus faecalis* and *Candida albicans*, with MIC values of 128 µg/mL and 512 µg/mL, respectively. Both extracts were ineffective against Gram-negative bacteria. The findings highlight species-specific therapeutic potential and support further investigation of these macroalgae as sources of multi-target natural products. Future work should focus on bioactivity-guided fractionation and in vivo validation.

Keywords: *Cystoseira foeniculacea, Sargassum vulgare, cytotoxicity, antimicrobial activity, methanolic extract, macroalgae.*

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1. Introduction

Cancer and infectious diseases persist as two of the most formidable challenges to global public health. Cancer remains a leading cause of mortality worldwide and represents a group of diseases for which effective treatment remains challenging despite current therapeutic approaches. The efficacy of many chemotherapeutic agents is often undermined by severe side effects and the emergence of drug-resistant cancer cells, further complicating disease management (Torre *et al*., 2016). Infectious diseases are also becoming progressively harder to manage, largely due to the alarming rise in antimicrobial resistance, which undermines the effectiveness of existing antibiotics and significantly narrows therapeutic options (Morrison & Zembower, 2020). Developing

next-generation anticancer and antimicrobial agents remains a major research focus in the pharmaceutical industry and the scientific community. However, the discovery and development of synthetic compounds is often a time-consuming and resource-intensive process and their clinical translation is frequently hampered by toxicity and safety concerns. Therefore, bioactive compounds derived from natural sources have been attracting increasing attention and are emerging as promising candidates for the development of novel therapeutic agents.

Recent studies have revealed that macroalgae contain a wide range of bioactive compounds with potential therapeutic effects against various diseases. As a result, many macroalgal species have been commercialized as functional foods or nutraceuticals. In addition to being rich sources of high-quality proteins, essential amino acids, polyunsaturated fatty acids, minerals and vitamins, macroalgae are also regarded as valuable reservoirs of potent antioxidants, phenolic compounds and flavonoids that may support human health and contribute to disease treatment. Polyphenols with antioxidant properties derived from macroalgae have been highlighted for their potential pharmaceutical benefits, particularly in disease conditions where oxidative stress and free radicals play a central role and may even contribute to their prevention (Pereira, 2020).

Cystoseira foeniculacea and *Sargassum vulgare* are among the most dominant edible macroalgae species of the order *Fucales* within the *Phaeophyceae* (brown algae) family in the Mediterranean Sea. Although these species are endemic, they typically grow in shallow coastal areas with high light penetration, often coexisting with other photosynthetic organisms. Compared to other Mediterranean algae, both species are relatively large and form dense habitats that support a diverse range of algal and animal species (Thibaut *et al*., 2005). Several studies have demonstrated that phytochemical constituents derived from *Sargassum* and *Cystoseira* species exhibit antiproliferative effects against various types of cancer and also possess antibacterial and antifungal activities against certain Gram-positive and Gram-negative pathogenic strains (Alzarea *et al*., 2021; Balaraman *et al*., 2020; Čagalj *et al*., 2022; González-Garrido *et al*., 2024; Sellimi *et al*., 2018).

Although several studies have explored the biological activities of *Cystoseira foeniculacea* and *Sargassum vulgare*, these investigations remain largely limited in scope and methodological consistency. Notably, significant disparities exist regarding the selected cell lines, assay protocols and extraction procedures. It is well-established that the polarity of extraction solvents can drastically alter the phytochemical profile of algal extracts, thereby affecting their observed biological activities (Messina *et al*., 2019). As such, the current body of literature falls short of providing a comprehensive understanding of the therapeutic potential of these species. Against this backdrop, the present study aims to address this gap by systematically assessing both the anticancer and antimicrobial properties of *Cystoseira foeniculacea* and *Sargassum vulgare* within a unified experimental framework.

In this study, the anticancer and antimicrobial activities of methanolic extracts obtained from *Cystoseira foeniculacea* and *Sargassum vulgare* were comprehensively evaluated. For cytotoxicity analysis, three different cancer cell lines were selected to reflect potential therapeutic targets: human hepatocellular carcinoma (HepG2), representing a primary site of metabolism due to the edible nature of seaweeds; estrogen receptor-positive human breast adenocarcinoma (MCF-7), to investigate hormone-dependent mechanisms and triple-negative breast cancer cells (MDA-MB-231), known for their aggressive and treatment-resistant phenotype. In the antimicrobial assays,

clinically relevant microorganisms were included, comprising Gram-positive bacteria (*Staphylococcus aureus*, *Enterococcus faecalis*, *Bacillus subtilis*), Gram-negative bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella enterica*) and fungal strains (*Candida albicans*, *Candida parapsilosis*, *Candida krusei*). This selective model system allowed for a multidimensional assessment of the biological activities of both macroalgal species across diverse cell types and pathogen groups, thereby distinguishing the study from previous literature and enhancing its novelty.

2. Materials and Methods

2.1. Extraction

The species *Sargassum vulgare* and *Cystoseira foeniculacea* used in this study were collected in 2023 from depths of 13-18 meters off the coasts of Yapıldakaltı (Çanakkale, Türkiye) and Boğazak (Serik, Antalya, Türkiye), respectively. Figure 1, shows the geographical locations in Türkiye where the macroalgae were collected. The harvested algal samples were dried and ground into a fine powder using a laboratory mill. For extraction, 265 mg and 90 mg of dried material from each species were macerated in 96% methanol for 24 hours. After extraction, the solutions were filtered using coarse filter paper and concentrated under reduced pressure at 40 °C with a rotary evaporator. The resulting extracts were lyophilized, weighed and stored in amber-colored bottles at +4 °C until further analysis.

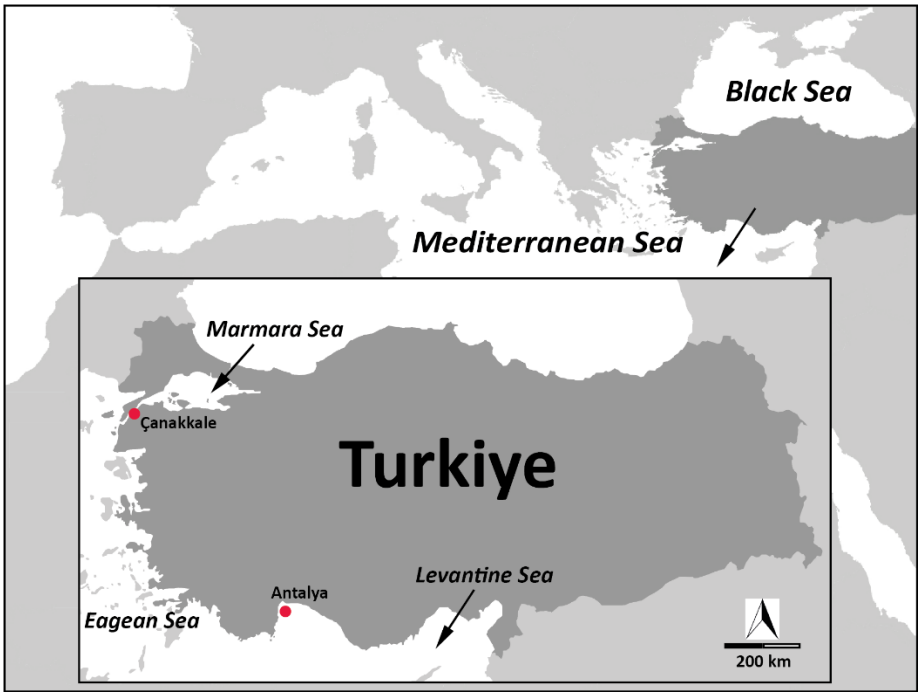

Figure 1. Geographical collection sites of *Cystoseira foeniculacea* and *Sargassum vulgare* along the coasts of Türkiye

2.2. Cytotoxic Effect via MTT Assay

The cytotoxic effects of the extracts were analyzed using the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay on HepG2, MCF-7

and MDA-MB-231 cancer cell lines. This colorimetric method relies on the reduction of MTT by mitochondrial dehydrogenases in metabolically active cells, leading to the formation of insoluble purple formazan crystals (Mosmann, 1983).

Briefly, cells were seeded in 96-well plates at a density of 6×10^3 cells per well and incubated for 24 hours to allow for attachment. Following incubation, the cells were treated with the extracts for 24 hours. At the end of the treatment period, the medium was replaced with MTT solution (1 mg/mL) and incubated for 2 hours at 37 °C. After incubation, the MTT solution was removed and the resulting formazan crystals were dissolved in DMSO. The optical density was measured at 550 nm using a microplate reader. Cell viability was expressed as a percentage by calculating the ratio of the absorbance of treated samples to that of the control, which was set at 100%.

2.3. Microorganisms

Refik Saydam culture collection (RSKK) and American Type Culture Collection (ATCC) strains were used in this study. *Staphylococcus aureus* ATCC 29213, *Enterococcus faecalis* ATCC 29212 and *Bacillus subtilis* RSKK 02021 as Gram-positive strains, *Escherichia coli* ATCC 25922, *Pseudomonas aeruginosa* ATCC 27853 and *Salmonella enterica* RSKK 04059 as Gram-negative strains and *Candida albicans* ATCC 90028, *Candida parapsilosis* RSKK 04057 and *Candida kruzei* ATCC 6257 as yeast strains were used. The strains were kept at -80°C in brain-heart infusion broth (Merck) with 10% glycerol before cultivation on tryptic soy agar (TSA, Merck).

2.4. Disk Diffusion Test

The inhibition zone diameters of the extracts were determined by disk diffusion test (Onal *et al*., 2023). Microorganisms were grown on TSA agar. Bacterial and fungal suspensions were prepared with sterile physiological saline and fresh colonies. The suspensions were adjusted to 0.5 McFarland turbidity using a densitometer device (Biosan, DEN-1). The suspensions were spread onto the agar plates using cotton swabs. Sterile blank disks (6 mm) (Oxoid) were placed on the plates and 10 µL of the extracts (200 µg/disk) were added to the disks. Mueller-Hinton agar (MHA) (Merck) plates were incubated at 37 °C for 24 h for bacteria and Sabouraud dextrose agar (SDA) (Oxoid) plates were incubated for 48 h for yeasts. Ciprofloxacin and fluconazole were used as antibiotic and antifungal reference drugs. All the experiments were studied in triplicate and the mean inhibition zone diameters were calculated.

2.5. Microdilution Method

The minimum inhibitory concentration (MIC) values of the extracts were investigated by the microdilution method (Kotmakçı *et al*., 2015). Fresh bacterial and fungal suspensions were prepared and adjusted to 0.5 McFarland turbidity by densitometer. The bacterial suspensions were diluted 10^{-2} and fungal suspensions were diluted 10^{-1}. 50 µL of Mueller-Hinton II broth (cation-adjusted) (Merck) for bacterial strains and Sabouraud dextrose broth (SDB) (Merck) for yeast strains were added to the sterile 96-well microplate wells. The extracts (50 µL) were added to the first wells and ½ serial dilutions were applied. 50 µL of bacterial and fungal suspensions were added to the wells and the microplates were incubated at 37 °C for 24 hours for bacterial strains and 48 hours for yeast strains. Fluconazole and ciprofloxacin were studied as reference

antimicrobial agents. All samples were tested in three replicates. The MIC values that prevented the growth of bacteria and fungi were determined.

3. Results

3.1. Antiproliferative Activity of the Extracts

The cytotoxic effects of the extracts obtained from *Cystoseira foeniculacea* and *Sargassum vulgare* were evaluated on HepG2, MCF-7 and MDA-MB-231 cancer cell lines based on IC_{50} values derived from cell viability percentages. The results revealed that the *Cystoseira foeniculacea* extract exhibited lower IC_{50} values across all cell lines compared to the *Sargassum vulgare* extract, indicating a higher cytotoxic activity.

Specifically, the IC_{50} values for *Cystoseira foeniculacea* were calculated as 35.25 µg/mL for HepG2, 105.5 µg/mL for MCF-7 and 3839 µg/mL for MDA-MB-231. In contrast, the IC_{50} values for *Sargassum vulgare* were 1860 µg/mL for HepG2, 2269 µg/mL for MCF-7 and 13,823 µg/mL for MDA-MB-231 (Figure 2). These findings suggest that the *Cystoseira foeniculacea* extract possesses notable cytotoxic potential, particularly against HepG2 and MCF-7 cell lines. Conversely, the *Sargassum vulgare* extract demonstrated weaker cytotoxic activity. The high IC_{50} values observed in both extracts for MDA-MB-231 cells suggest a limited cytotoxic effect against triple-negative breast cancer.

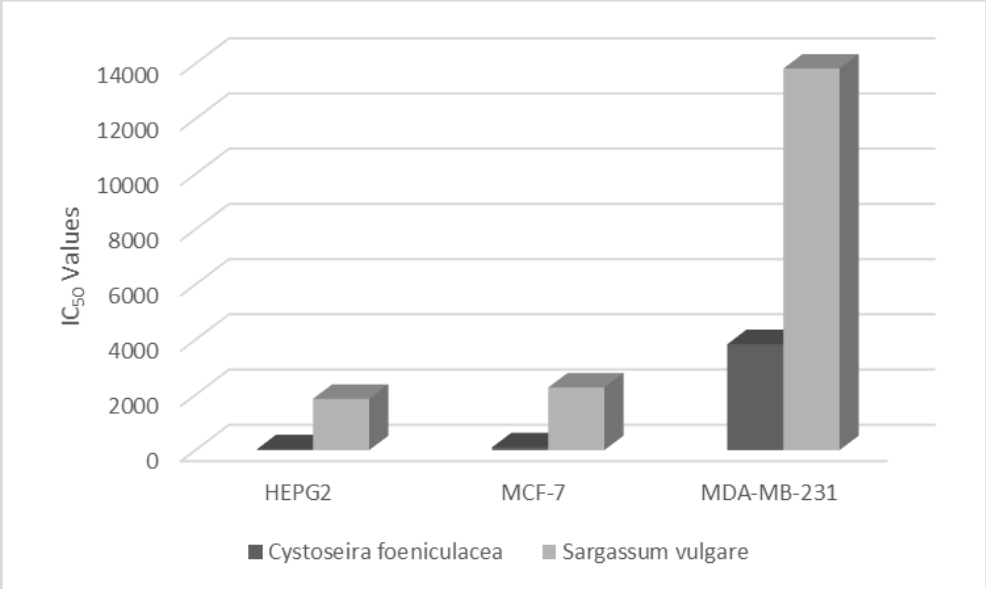

Figure 2. IC_{50} values of *Cystoseira foeniculacea* and *Sargassum vulgare* on HepG2, MCF-7 and MDA-MB-231 cell lines

3.2. Disk Diffusion Test

The antibacterial and antifungal activities of the extracts against Gram-positive bacteria, Gram-negative bacteria and yeast strains were evaluated using the disk diffusion method and the inhibition zone diameters are presented in Table 1. The *Cystoseira foeniculacea* extract exhibited inhibition zones against *S. aureus* (7 mm) and *E. coli* (8 mm), while no notable activity was observed against the other microorganisms. In contrast, the *Sargassum vulgare* extract demonstrated inhibition only against *E. faecalis*

(8 mm). Both extracts showed limited efficacy against Gram-negative bacteria. No inhibition zones were detected against the yeast strains using the disk diffusion method.

Table 1. The results of the disk diffusion test and microdilution method

Microorganisms		Mean inhibition zone diameter values (millimeter)		Minimum inhibitory concentration values (µg/mL)	
		CF extract	SV extract	CF extract	SV extract
Gram-positive bacteria	***S. aureus***	7.00±0.00	-	512	512
	E. faecalis	-	8.00±0.00	1024	128
	B. subtilis	-	-	2048	256
Gram-negative bacteria	***E. coli***	8.00±0.00	7.00±0.00	>4096	>4096
	P. aeruginosa	-	-	>4096	>4096
	S. enterica	-	-	>4096	>4096
Yeast strains	***C. albicans***	-	-	2048	512
	C. parapsilosis	-	-	4096	>4096
	C. kruzei	-	-	4096	>4096

Note: Reference antimicrobial agents used were ciprofloxacin (antibacterial) and fluconazole (antifungal)
CF extract: Cystoseira foeniculacea extract; SV extract: Sargassum vulgare extract;
(-): no inhibition zone

3.3. Minimum Inhibitory Concentration (MIC) Values of the Extracts

The MIC values of the extracts were determined using the microdilution method and are summarized in Table 1. *Sargassum vulgare* extract exhibited the strongest antibacterial activity, showing the lowest MIC value (128 µg/mL) against *E. faecalis*. In contrast, *Cystoseira foeniculacea* showed moderate antibacterial activity against *S. aureus* with a MIC value of 512 µg/mL. Both extracts were found to be ineffective against Gram-negative bacteria, as their MIC values were ≥4096 µg/mL. For *C. albicans*, *Sargassum vulgare* demonstrated a lower MIC value (512 µg/mL) compared to *Cystoseira foeniculacea* (2048 µg/mL), indicating a relatively higher antifungal activity. However, neither extract showed significant antifungal activity against *C. parapsilosis* or *C. krusei*. These findings suggest that *Sargassum vulgare* exhibits stronger antimicrobial activity, particularly against *E. faecalis* and *C. albicans*, while both extracts display limited efficacy against Gram-negative bacteria and other yeast strains.

4. Discussion

This study aims to evaluate the antiproliferative and antimicrobial activities of extracts obtained from *Sargassum vulgare* and *Cystoseira foeniculacea*, thereby elucidating their pharmaceutical potential. Macroalgae are considered promising sources for pharmaceutical and biotechnological applications due to their rich content of bioactive compounds such as phenolics, terpenoids and polysaccharides. In recent years, there has been growing interest in exploring these marine-derived compounds as potential therapeutic agents. However, the available literature on the biological activities of *Sargassum vulgare* and *Cystoseira foeniculacea* remains limited. To date, no comprehensive studies have been conducted evaluating both the anticancer and antimicrobial properties of these two species simultaneously. In this context, the present

work addresses a significant gap in the literature by providing a broader investigation into the therapeutic potential of these macroalgae.

In this study, the cytotoxic effects of methanolic extracts from *Cystoseira foeniculacea* and *Sargassum vulgare* were evaluated on HepG2, MCF-7 and MDA-MB-231 cell lines. *Cystoseira foeniculacea* exhibited greater cytotoxic activity, as indicated by lower IC_{50} values in HepG2 and MCF-7 cells. Notably, IC_{50} values were calculated as 35.25 µg/mL for HepG2 and 105.5 µg/mL for MCF-7, demonstrating significant antiproliferative effects. In contrast, *Sargassum vulgare* showed higher IC_{50} values across all cell lines, with a particularly limited cytotoxic response observed in MDA-MB-231 cells (IC_{50}: 13,823 µg/mL).

Previous studies have indicated that polyphenolic compounds isolated from *Cystoseira* species can induce apoptosis in cancer cell lines (Abu-Khudir *et al*., 2021; Chen *et al*., 2024; Zbakh *et al*., 2020). In this context, the prominent antiproliferative activity observed in the MCF-7 cell line, which is estrogen receptor (ER)-positive, may be related to the presence of potential phytoestrogen compounds in *Cystoseira foeniculacea* (Markov *et al*., 2018). In contrast, no significant cytotoxicity was observed in the triple-negative MDA-MB-231 cell line (IC_{50}= 3839 µg/mL), which is known to carry a p53 mutation and display resistance to apoptosis-inducing agents (Lev, 2020). Therefore, the selective cytotoxicity of *Cystoseira foeniculacea* may be attributed to the interaction between extract constituents and the molecular characteristics of specific cancer cell lines.

On the other hand, the methanolic extract of *Sargassum vulgare* exhibited relatively weak antiproliferative activity in all tested cell lines, with the highest IC_{50} value observed in the MDA-MB-231 cells (13823 µg/mL). This suggests that the polar extract of *Sargassum vulgare* has limited cytotoxic potential. In contrast to our findings, a study using apolar solvent fractions (n-hexane and dichloromethane) of *Sargassum fulvellum* reported significant antiproliferative activity against MDA-MB-231 cells through cell cycle arrest and pro-apoptotic mechanisms (Yoon *et al*., 2010). Similarly, in *Sargassum fluitans*, dichloromethane and chloroform extracts demonstrated stronger cytotoxicity compared to the methanol extract, which showed minimal effect on MCF-7 and MDA-MB-231 cell lines (González-Garrido *et al*., 2024). These findings highlight the influence of solvent polarity on the chemical profile and biological activity of algal extracts (Monteiro *et al*., 2020).

Bioactive compounds such as fucosterol, isolated from *Sargassum* species, have been reported to induce cell death in various cancer cell lines, including HepG2, HCT-116 and MCF-7 (Khanavi *et al*., 2012; Kirindage *et al*., 2022; Meinita *et al*., 2021). However, the weaker cytotoxic effect observed in our study may be due to low concentrations or absence of such compounds in the methanolic extract of *Sargassum vulgare*. Moreover, in a study involving silver nanoparticles synthesized from *Sargassum vulgare* have shown strong cytotoxicity in HepG2 and other cancer cell lines, which could be attributed to enhanced bioavailability and cellular uptake mechanisms associated with the nanoparticulate form (Hamouda & Aljohani, 2024). Moreover, it should be noted that the phytochemical composition and bioactivity of macroalgae can also vary depending on the season of collection, as reported in previous studies, further emphasizing the need for standardized sampling protocols when assessing biological potential (Mansur *et al*., 2020). Taken together, these findings suggest that the chemical composition of the algal species, the extraction method employed and the season of collection play critical roles in determining antiproliferative efficacy. Future research should focus on testing

fractionated extracts on different cancer models and identifying the active constituents responsible for the observed biological effects.

The antimicrobial activity results revealed that both species exhibited limited yet selective antimicrobial profiles. The extract of *Cystoseira foeniculacea* showed inhibition only against *S. aureus*, whereas *Sargassum vulgare* extract demonstrated activity solely against *E. faecalis*. According to the MIC data obtained via the microdilution method, *Sargassum vulgare* displayed a stronger antibacterial effect against *E. faecalis* with a notably low MIC value of 128 µg/mL. In contrast, both extracts showed MIC values exceeding 4096 µg/mL against Gram-negative bacteria, indicating a lack of efficacy against these strains. This limited activity against Gram-negative strains may be attributed to their outer membrane structure and the presence of lipopolysaccharides, which act as a permeability barrier and can modulate inflammatory responses. Indeed, Karpiński and Adamczak (2019) reported that the lipopolysaccharide component of Gram-negative bacteria contributes to infection severity and resistance to bioactive compounds (Karpiński & Adamczak, 2019). Additionally, while Patra et al. (2008) observed strong antimicrobial activity of *Sargassum* methanolic extracts against *E. coli*, they noted that high concentrations were necessary to achieve this effect. Similarly, Karkhaneh Yousefi et al. (2020) emphasized that although fucoxanthin-rich extracts showed inhibitory activity against *E. coli,* other compounds, such as phlorotannins, might also play a crucial role in antibacterial efficacy.

In terms of antifungal activity, *Sargassum vulgare* exhibited a moderate inhibitory effect against *Candida albicans* (MIC: 512 µg/mL), while no significant activity was observed against *Candida parapsilosis* and *Candida krusei*. These findings suggest that certain compounds derived from macroalgae may possess antifungal potential; however, such effects likely vary depending on both species and chemical composition. Previous studies have reported strong in vitro antifungal activity of various marine algae, such as *Alaria esculenta, Fucus vesiculosus* and *Spirulina platensis,* particularly against plant pathogenic fungi, with the observed effects attributed to the presence of bioactive constituents including phlorotannins, terpenes, polysaccharides and fatty acids (Abd El-Baky *et al*., 2008; Awad, 2000; Jayaraj *et al*., 2008; Mundt *et al*., 2003). Similarly, methanolic extracts and phenolic- or alkaloid-rich fractions derived from brown algae in the same family, such as *Sargassum muticum*, have demonstrated high inhibition rates (80-90%) against fungal strains like *Cladosporium globosum* and *Aspergillus nidulans*, including resistant nosocomial isolates (Sanz *et al*., 2023). However, unlike these findings, our results showed that *Sargassum vulgare* possessed only limited antifungal activity, particularly against *C. krusei* and *C. parapsilosis*. This discrepancy could be attributed to interspecies phytochemical differences, the use of crude methanolic extracts instead of enriched fractions or the different susceptibility profiles of the tested fungal strains. Our study focused on clinically relevant *Candida* species, while previous studies often targeted plant-derived or airborne fungi, which may explain the differences in sensitivity. Additionally, the higher efficacy reported for *Sargassum muticum* might be linked to its invasive ecological adaptation, which promotes the production of diverse secondary metabolites with antifungal properties (Sanz *et al*., 2023). Finally, mechanisms such as cell wall synthesis inhibition and disruption of fungal biofilms by phenolic compounds like phlorotannins and organic acids including caffeic and cinnamic acid have been proposed to underlie the antifungal activity observed in these algal species (Campos *et al*., 2018; Echave *et al*., 2022).

This study provides an integrative assessment of both the cytotoxic and antimicrobial activities of methanolic extracts obtained from *Cystoseira foeniculacea* and *Sargassum vulgare*. While prior research has explored the biological activities of various species within the same family, studies focusing specifically on these two species remain limited, particularly those employing comparable experimental frameworks. In most previous studies, either different cancer cell lines, alternative extraction solvents or varying exposure protocols have been used, making direct comparisons difficult and potentially contributing to the observed variability in biological responses. In this respect, our approach offers a distinct methodological perspective by evaluating the therapeutic potential of these macroalgae through standardized in vitro models involving human cancer cell lines and clinically relevant microbial strains. The selection of *HepG2*, *MCF-7* and *MDA-MB-231* cell lines was strategic-*HepG2* represents hepatocellular carcinoma and is often used for the safety evaluation of edible compounds, while the two breast cancer lines differ in hormone receptor status. The differential sensitivity observed, particularly the higher susceptibility of the estrogen receptor-positive *MCF-7* cells, may be linked to the phytoestrogen potential of compounds present in *Cystoseira foeniculacea*. Similarly, the antimicrobial component of the study was designed to capture a broad spectrum of action. Both Gram-positive and Gram-negative bacteria, as well as three different *Candida* species, were included to allow comprehensive evaluation. The use of both diffusion and dilution-based assays further strengthened the reliability of the antimicrobial findings. Among the key findings, *Cystoseira foeniculacea* demonstrated marked cytotoxic activity, especially against *HepG2* and *MCF-7*, whereas *Sargassum vulgare* showed limited antiproliferative effects but exhibited selective antimicrobial activity, particularly against *E. faecalis* and *C. albicans*. These differential outcomes highlight the species-specific bioactivity profiles and suggest that each species may harbor distinct compounds suitable for targeted pharmacological applications.

Nevertheless, several limitations should be acknowledged. First, the use of methanol as the sole extraction solvent may have constrained the chemical diversity of the extracts; previous studies have demonstrated that bioactivity can significantly vary depending on the polarity of the solvent used. Second, although the absence of a positive control group in cytotoxicity assay could be perceived as a limitation, it was deliberately excluded in this study to focus solely on the intrinsic biological activity of the algal extracts. This approach allowed for a more direct comparison of the relative cytotoxic and antimicrobial potentials of *Cystoseira foeniculacea* and *Sargassum vulgare* without the confounding influence of reference drugs. Given the exploratory nature of this study and its emphasis on preliminary screening, the design was tailored to assess bioactivity in a standardized in vitro setting. However, future studies should incorporate appropriate positive controls to enable benchmarking against clinically used agents and to further validate the therapeutic relevance of the observed effects. Moreover, using extraction protocols with solvents of varying polarities would provide access to a broader spectrum of secondary metabolites, potentially enhancing the biological activity profiles of the extracts. In addition, conducting basic phytochemical screening could offer insight into the chemical constituents responsible for the observed effects and guide targeted bioactivity investigations.Finally, all experiments were conducted in vitro; therefore, in vivo validation and further mechanistic studies are essential to confirm these results.

5. Conclusion

In conclusion, this study provides an evaluation of the cytotoxic and antimicrobial activities of methanolic extracts derived from *Cystoseira foeniculacea* and *Sargassum vulgare*. *Cystoseira foeniculacea* exhibited pronounced cytotoxic effects, particularly against *HepG2* and *MCF-7* cell lines, whereas *Sargassum vulgare* demonstrated selective antimicrobial activity against *Enterococcus faecalis* and *Candida albicans*. These results highlight the species-specific therapeutic potential of these macroalgae and support the development of multi-target natural product-based therapeutic agents. However, further studies including bioactivity-guided fractionation, structural identification of active compounds and in vivo validations are essential to advance their pharmaceutical applicability.

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