

Bioactivities of macroalgae harvested in Morocco from January 2016 to August 2026

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ABSTRACT

Macroalgae from the Moroccan Atlantic and Mediterranean coasts have been investigated as sources of bioactive preparations for biomedical, agricultural and environmental applications. This narrative review updates the 2016 overview of Moroccan seaweed bioactivities and examines experimental studies published from January 2016 through August 2026. The synthesis focuses on locally harvested macroalgae, the preparations tested and the biological models used. The literature covers antioxidant and antimicrobial screening, digestive-enzyme inhibition, toxicity and cancer-cell assays, antiviral polysaccharides, vascular responses, wound healing, cyanobacterial growth inhibition and crop protection. Studies from Nador lagoon broaden the evidence for green and red algae, while work on *Fucus spiralis*, *Sargassum muticum* and sulfated polysaccharides extends the range of experimental applications. Seasonal comparisons and studies of extraction and drying show why activity must be interpreted in relation to the harvested and processed material. Animal experiments provide proof of concept for selected preparations, although efficacy and safety in humans remain unestablished. Differences in extraction, assay conditions, controls and replication restrict comparisons across studies. Chemical profiling and molecular docking add useful information but do not, on their own, identify the constituents responsible for activity or validate their targets. Further progress depends on traceable collection, reproducible preparation, activity-guided characterization and safety testing appropriate to the intended application.

Keywords: Moroccan macroalgae, bioactivity; extraction, sulfated polysaccharides, biocontrol, enzyme inhibition, evidence appraisal.

INTRODUCTION

The Atlantic and Mediterranean coasts of Morocco provide contrasting habitats for macroalgae and a geographically defined resource for biological screening. Farid et al. (2016) synthesized earlier antimicrobial, antiviral, anti-inflammatory and antifungal studies. An updated review is useful because the subsequent literature extends beyond crude antimicrobial extracts to enzyme inhibition, chemical profiling, polysaccharide preparations and assays performed in plants and animals. The relevant unit of evidence is a defined

algal preparation obtained from a documented collection, rather than a species name alone.

This distinction matters when evaluating claims of practical value. An extract that scavenges a chemical radical, inhibits a microbial culture or reduces cancer-cell viability does not by itself demonstrate a therapeutic effect. Similarly, a plant growth response or an inhibitory effect on cyanobacteria does not establish field effectiveness. Nevertheless, these findings can identify preparations worth further investigation when their provenance, composition and experimental performance are reproducible.

This review brings together experimental studies of macroalgae harvested in Morocco, compares their preparations and biological endpoints, and examines the methodological limits that affect interpretation. Particular attention is given to collection site, season, salinity and extraction conditions, alongside chemical characterization and safety. Publications from 2016 are retained to cover the transition from the earlier review to the subsequent literature.

The appraisal considers provenance, taxonomic identification, extraction procedures, dose–response design, controls, replication and safety or selectivity. Results are synthesized qualitatively because the preparations, units and endpoints differ substantially. No numerical risk-of-bias score is assigned, and potencies are not pooled across unrelated assays.

BIOACTIVITY EVIDENCE

Antioxidant screening and enzyme inhibition

Antioxidant screening is a recurring component of this literature. Studies include *Gracilaria bursa-pastoris* from Nador lagoon and a survey of 86 species from the El Jadida coast (Ramdani et al., 2017; Chibi et al., 2019). Antioxidant and antibacterial screening of *Cystoseira humilis* also formed part of an earlier study of its fatty-acid composition (Belattmania et al., 2016). In the seven-species brown-algal study by Samri et al. (2019), preparations of *Bifurcaria bifurcata* and *Fucus spiralis* were among the most active under the tested conditions. Hsaine et al. (2019) documented additional responses in red algae. The variation between solvent fractions makes these studies useful for selecting preparations for further work, but provides no basis for a universal ranking of species.

Studies of *Gracilaria bursa-pastoris* and *Ulva lactuca* from Nador lagoon combine chemical profiling with antioxidant tests, α -amylase and α -glucosidase inhibition, and molecular docking (Ouahabi et al., 2023; Ouahabi et al., 2024). A subsequent investigation applied a comparable combination of approaches to *Caulerpa prolifera* (Ouahabi et al., 2025). The enzyme assays provide a more specific biochemical endpoint than radical scavenging alone. Nevertheless, inhibition in vitro does not demonstrate reduced blood glucose

in an organism, and comparisons with acarbose apply to the assay conditions used. Docking can guide subsequent experiments, but the activity of an extract cannot be assigned to an annotated constituent without testing that constituent.

Postharvest processing is another source of variation. El Majnaoui et al. (2025) compared drying methods for Moroccan *Gracilaria gracilis* and *Ulva lactuca*, including effects on phenolic measurements, antioxidant assays and surface colour. Together with the wild/cultivated and regional comparisons (El-Majnaoui et al., 2023; El Majnaoui et al., 2024), this work indicates that measured activity is a property of the harvested and processed preparation, not only of the taxon. Sabir et al. (2025) further reported antioxidant responses in crude polysaccharides from three *Cystoseira* taxa. Co-extracted phenolics and proteins remain possible contributors to those responses.

Antibacterial and antifungal activity

Studies from Agadir report antibacterial and antifungal responses in brown, red and green macroalgae (Fayzi et al., 2020; Fayzi et al., 2022). Seven brown algae from Sidi Bouzid were compared using different extraction solvents (Samri et al., 2020). Antimicrobial investigations of *Laminaria ochroleuca* and *Bornetia secundiflora* further extend the evidence from El Jadida (Boujaber et al., 2019; Oumaskour et al., 2019). Farid (2024) screened 17 Oualidia species and identified active preparations, including *C. humilis*, *B. bifurcata* and *Asparagopsis armata*. This is useful screening evidence; the report does not establish a purified antimicrobial molecule. Diffusion-zone sizes cannot be compared directly across studies without accounting for the extract mass, solvent, inoculum and diffusion behaviour.

Two studies published in 2024 extend the antifungal evidence. El Mouns et al. (2024) tested organic extracts of red algae from Sidi Bouzid against environmental and clinical fungal isolates. Younssi Tarhzouti et al. (2024) examined alkaloid and phenolic-rich fractions of seven brown algae and selected *Sargassum muticum* for further analysis. A phenolic-rich fraction had reported minimum inhibitory concentrations (MICs) of 3.12–6.25 $\mu\text{g/mL}$ against airborne toxigenic isolates. These measurements describe the tested fraction–isolate combinations; broader efficacy requires comparable susceptibility methods and an assessment of toxicity.

Brahimi et al. (2026) combined antioxidant and antimicrobial assays with ultra-performance liquid chromatography–high-resolution mass spectrometry (UPLC–HRMS) Orbitrap profiling of *Ulva lactuca* and *Sargassum muticum* from Sidi Bouzid. Fayzi et al. (2026) investigated the volatile preparation of *Bifurcaria bifurcata* from northern Agadir using hydrodistillation, gas chromatography–mass spectrometry (GC–MS) and antioxidant/antibacterial assays. Both studies add chemical context to screening. However, an annotated chromatographic peak, its relative abundance and a correlated extract activity are different types of evidence; activity-guided isolation is needed to assign a causal contribution to an individual constituent.

Cytotoxicity, inflammation and vascular effects

Sphaerococcus coronopifolius collected in Mediterranean Morocco has been investigated in cancer-cell and inflammatory-response models (Salhi et al., 2018). Grozdanic et al. (2020) assessed *Fucus spiralis* extracts and fractions against cancer cells alongside a non-tumour comparator, and also examined endothelial migration and tube formation. Thus, vascular endpoints were already represented in this literature in 2020. A subsequent *F. spiralis* study combined antiproliferative assays, chemical characterization and docking (Boutjagualt et al., 2022a). Together, these approaches help prioritize active fractions, although computational binding predictions remain distinct from experimentally established mechanisms.

Toxicity screening must be distinguished from selective pharmacological activity. Lasky et al. (2019) examined erythrocyte haemolysis, a safety-related endpoint. Cancer-cell responses reported for *Laminaria ochroleuca* and *Bornetia secundiflora* (Boujaber et al., 2019; Oumaskour et al., 2019) require a different interpretation and should be assessed alongside exposure-matched non-tumour controls and complementary measures of viability or cell death.

Oumaskour et al. (2017) compared nine macroalgae collected at Sidi Bouzid across four seasons. Dichloromethane/methanol (DCM/MeOH, 1:1) extracts were tested against *Artemia salina* nauplii over 24 hours. Mortality was generally higher for spring and summer preparations, especially among red and brown algae. This assay

measures general toxicity in an invertebrate model; it does not establish tumour-cell selectivity.

Polysaccharide preparations extend the range of models. Boujhoud et al. (2024) report anti-angiogenic, anti-inflammatory and anticoagulant effects of material from *Cystoseira humilis* collected at El Jadida. *Osmundea pinnatifida* polysaccharide-rich material instead shows pro-angiogenic and wound-healing activity (Boujhoud et al., 2025). These opposing vascular directions are not interchangeable: they concern different preparations, experimental systems and possible applications. A chorioallantoic membrane assay measures an in ovo response; it should be distinguished from mammalian efficacy and from HET-CAM irritation testing.

Antiviral polysaccharides

Benhniya et al. (2025) investigated a *Placodium cartilagineum* polysaccharide preparation with antiviral, inflammation-related and anti-angiogenic endpoints. The reported half-maximal effective concentration (EC₅₀) against herpes simplex virus type 1 (HSV-1) was $3.84 \pm 2.8 \mu\text{g/mL}$. This concentration describes an experimental response to the preparation, not a therapeutic dose.

A sulfated polysaccharide from *Codium tomentosum* inhibited HSV-1 with an EC₅₀ of $12.22 \pm 2.90 \mu\text{g/mL}$ and a half-maximal cytotoxic concentration (CC₅₀) above 200 $\mu\text{g/mL}$ in the tested system (Benhniya et al., 2026b). These results indicate a preliminary separation between antiviral activity and cytotoxicity under those conditions. Antibacterial, antifungal and chemical antioxidant responses were also reported. A conference paper on polysaccharide preparations from seven macroalgae provides additional preliminary antiviral observations (Benhniya et al., 2026a). Related publications should be interpreted with attention to shared preparations and experiments rather than automatically counted as independent confirmation.

Animal evidence and wound healing

Animal evidence includes the study by El Kafhi and Khelifi (2025), who evaluated *Halopitys incurvus* essential oil from the El Jadida coast in surgically induced wounds in Wistar rats. This work extends wound-healing research beyond polysaccharide preparations. It complements the *Osmundea pinnatifida* study (Boujhoud et al., 2025), although

differences in formulation, dose and wound model prevent a direct comparison of efficacy.

Kabbali et al. (2026) studied *Sargassum muticum* in 35 Wistar rats allocated to five groups, including cafeteria-diet controls, seaweed-supplemented groups and an orlistat comparator. After eight weeks, the supplemented groups showed improved histological features in several organs. This is an animal proof of concept for a dietary preparation, not identification of a specific active molecule. Attribution to phlorotannins, fucoxanthin or polysaccharides requires component-resolved experiments, and changes in food intake or diet composition must be considered when interpreting the effects.

Aquatic biocontrol, plant responses and pest control

Moroccan seaweed preparations have been assessed against cyanobacteria in two distinct lines of work: extract screening (El Amrani Zerifi et al., 2019) and essential-oil evaluation (El Amrani Zerifi et al., 2020). Growth inhibition in these systems supports further investigation, but an environmentally useful treatment also requires evidence on cyanotoxin release, persistence and toxicity to non-target organisms. The origin of a

product from marine biomass does not establish that it is ecologically safe.

Agricultural studies include tomato growth promotion by polysaccharide-enriched extracts (Mzibra et al., 2018; Mzibra et al., 2021). Fucoidans elicited defence responses in date-palm roots (Bouissil et al., 2020). Other preparations stimulated olive-leaf defences or acted as a *Codium decorticatum* glycoprotein elicitor in tomato (Aitouguinane et al., 2022b; Aitouguinane et al., 2022a). Protection of tomato against *Botrytis cinerea* was assessed in separate studies (Bahammou et al., 2017; Mzibra et al., 2022). Growth stimulation, defence-marker induction and disease suppression are distinct endpoints. A defence enzyme response should not be equated with disease control without a pathogen challenge, and nutrient effects should be separated from specific elicitor activity.

Pest-control studies include *Fucus spiralis* essential oil tested against pupae and adults of *Ceratitis capitata* (Boutjagualt et al., 2022b) and ethanolic brown-algal extracts assessed against root-knot nematodes reported as *Meloidogyne spp.* (Belmouden et al., 2025). These findings broaden the agricultural endpoints considered for Moroccan macroalgae. For each study, Table 1 records the source, published taxon, collection location, preparation, experimental endpoint and principal

Table 1. Experimental studies of macroalgae harvested in Morocco

Study / year	Published taxon / collection	Preparation	Model / endpoint	Finding and interpretation (concentrations: µg/mL or mg/mL, as specified)
Belattmania et al. (2016)	<i>Cystoseira humilis</i> Atlantic coast south of El Jadida	Methanolic material	Antioxidant; antibacterial	Screening and fatty-acid profiling; nutritional lipid indices are not clinical outcomes.
Ramdani et al. (2017)	<i>Gracilaria bursa-pastoris</i> Nador lagoon	Ethanol/water extracts	DPPH; phenolics	Antioxidant screening; extraction-dependent response.
Bahammou et al. (2017)	<i>Cystoseira tamariscifolia</i> ; <i>Bifurcaria bifurcata</i> Sidi Bouzid	Hexane; water	<i>Botrytis cinerea</i> ; tomato postharvest test	Inhibition of <i>Botrytis cinerea</i> and protection of inoculated tomato fruit.
Oumaskour et al. (2017)	<i>Bornetia secundiflora</i> ; <i>Caulacanthus ustulatus</i> ; <i>Gelidium sesquipedale</i> ; <i>Ulva lactuca</i> ; <i>Codium tomentosum</i> ; <i>Enteromorpha compressa</i> ; <i>Fucus spiralis</i> ; <i>Saccorhiza polyschides</i> ; <i>Laminaria ochroleuca</i> , Sidi Bouzid, El Jadida; four seasons	DCM/MeOH (1:1)	<i>Artemia salina</i> nauplii; 24 h mortality	Season-dependent toxicity; generally greater in spring and summer.
Mzibra et al. (2018)	17 macroalgal species Moroccan coast	Polysaccharide-enriched extracts	Tomato germination and growth	Growth-promoting preparations identified under the tested conditions.
Salhi et al. (2018)	<i>Sphaerococcus coronopifolius</i> Mediterranean Morocco	Extracts/fractions	Cancer-cell assays; inflammatory response	Antiproliferative and anti-inflammatory findings; clinical translation unestablished.

Study / year	Published taxon / collection	Preparation	Model / endpoint	Finding and interpretation (concentrations: µg/mL or mg/mL, as specified)
Chibi et al. (2019)	86 species El Jadida coast	Organic crude ex- tracts	DPPH screening	Antioxidant responses varied among species and extract preparations.
Lasky et al. (2019)	<i>Cystoseira myriophylloides</i> El Jadida	Solvent extracts/ fraction	Human erythrocyte haemolysis	Haemolytic responses char- acterize erythrocyte toxicity.
El Amrani Zerrifi et al. (2019)	Moroccan seaweeds Moroccan collection	Extracts	Toxic cyanobacteria	Inhibitory response; non-tar- get safety requires separate assessment.
Boujaber et al. (2019)	<i>Laminaria ochroleuca</i> El Jadida	Extracts	Antimicrobial; cancer- cell assays	Antimicrobial and cancer-cell responses reported.
Oumaskour et al. (2019)	<i>Bornetia secundiflora</i> El Jadida	Extracts	Antibacterial; cytotoxic	Antibacterial and cytotoxic responses reported.
Samri et al. (2019)	Seven brown algae Sidi Bouzid; April 2015	Five solvent sys- tems	DPPH; phenolic as- says	<i>B. bifurcata</i> and <i>F. spiralis</i> preparations among the strongest within this experi- ment.
Hsaine et al. (2019)	Red seaweeds Sidi Bouzid	Solvent extracts	DPPH; phenolic as- says	Adds red-algal screening; response differs with species and solvent.
Fayzi et al. (2020)	<i>B. bifurcata</i> ; <i>Corallina spp.</i> ; <i>Ulva fasciata</i> Agadir region	Methanol	Bacterial growth inhibi- tion	Antibacterial screening with susceptibility measures; compare only matched con- ditions.
Grina et al. (2020)	Five Moroccan seaweeds Moroccan coast	Ethanol	Antioxidant; enzyme inhibition; LC–MS/MS	Multiparametric screening; individual enzyme endpoints require method-specific interpretation.
El Amrani Zerrifi et al. (2020)	Three seaweeds Moroccan coast	Essential oils	Cyanobacteria growth/ physiology	Aquatic biocontrol proof of concept; environmental safety not established by inhibition alone.
Samri et al. (2020)	Seven brown algae Sidi Bouzid	Five solvent sys- tems	Six bacteria; two fungi	Antibacterial and antifungal screening of solvent extracts.
Grozdanic et al. (2020)	<i>Fucus spiralis</i> Moroccan coastline	DCM/MeOH and solvent fractions	Cancer cells; MRC-5; endothelial assays; α-glucosidase	Fraction-dependent respons- es in cancer-cell, endothelial and enzyme assays.
Bouissil et al. (2020)	<i>Bifurcaria bifurcata</i> ; <i>Fucus spiralis</i> , Moroccan coast	Fucoidans	Date-palm root de- fence elicitation	Defence responses reported; distinguish elicitation from disease protection.
Mzibra et al. (2021)	17 Moroccan seaweeds Moroccan coast	Polysaccharide- enriched extracts	Tomato germination, metabolomics and growth	Germination, metabolic and growth responses to sea- weed preparations.
Fayzi et al. (2022)	<i>Bifurcaria bifurcata</i> ; <i>Corallina officinalis</i> ; <i>Codium tomentosum</i> ; <i>Ulva fasciata</i> , Agadir	Aqueous extracts	Antioxidant; posthar- vest fungi	Antioxidant responses and inhibition of postharvest fungi.
Aitouguinane et al. (2022b)	Green and brown seaweeds Moroccan collection	Polysaccharides and derivatives	Olive-leaf defence responses	Elicitor activity; no automatic inference of orchard-level efficacy.
Boutjagualt et al. (2022a)	<i>Fucus spiralis</i> , Sidi Bouzid–El Jadida	Extract and active fractions	Cancer-cell prolifera- tion; chemical analysis; docking	Chemical assignments and docking are not equivalent to experimentally validated targets.
Aitouguinane et al. (2022a)	<i>Codium decorticatum</i> Moroccan collection	Sulfated glycopro- tein	Tomato defence induc- tion	Induction of tomato defence responses by a glycoprotein preparation.
Mzibra et al. (2022)	Eight macroalgal species Moroccan coast	Polysaccharide- enriched extracts	Tomato; <i>Botrytis ci- nerea</i>	Defence response and pro- tection reported; no automat- ic inference of field efficacy.
Boutjagualt et al. (2022b)	<i>Fucus spiralis</i> Sidi Bouzid; March 2017	Essential oil	<i>Ceratitis capitata</i> pu- pae and adults	Insecticidal activity adds a distinct pest-control axis; non-target tests needed.
El-Majnaoui et al. (2023)	Four wild/cultivated species Moroccan Atlantic coast	Species-specific preparations	DPPH/FRAP; compo- sition	Nutritional and antioxidant comparison of wild and culti- vated biomass.

Study / year	Published taxon / collection	Preparation	Model / endpoint	Finding and interpretation (concentrations: µg/mL or mg/mL, as specified)
Ouahabi et al. (2023)	<i>Gracilaria bursa-pastoris</i> Nador lagoon	Multiple solvents; maceration/Soxhlet	Antioxidant; α-amylase/ α-glucosidase; docking	Digestive-enzyme inhibition in vitro; no demonstration of blood-glucose lowering.
El Majnaoui et al. (2024)	<i>Gelidium sesquipedale</i> Four Moroccan Atlantic sites	Extracts	Antioxidant; nutritional composition	Regional comparison of composition and antioxidant responses.
Farid (2024)	17 species, including <i>C. humilis</i> , <i>B. bifurcata</i> , <i>A. armata</i> , Oualidia lagoon	Crude extracts	Antimicrobial screening	Active crude extracts identified among the screened species.
Boujhoud et al. (2024)	<i>Cystoseira humilis</i> El Jadida; March–May 2023	Sulfated polysaccharide PSCH	Anti-angiogenic; anti-inflammatory; coagulation	Anti-angiogenic, inflammation-related and anticoagulant responses.
Ouahabi et al. (2024)	<i>Ulva lactuca</i> Nador lagoon	Multiple solvents; maceration/Soxhlet	Antioxidant; α-amylase/α-glucosidase; docking	In vitro enzyme-inhibitory activity; comparisons with acarbose are assay-specific.
El Mouns et al. (2024)	Seven red algae Sidi Bouzid	Organic extracts	Environmental/clinical fungi; GC–MS	Extends fungal targets; active extract does not establish a causal isolated compound.
Younssi Tarhzouti et al. (2024)	Seven brown algae; <i>Sargassum muticum</i> selected El Jadida coastline	Alkaloid and phenolic-rich fractions	Four fungal isolates; LC–MS/GC–MS	Phenolic fraction MIC 3.12– 6.25 µg/mL against airborne toxicogenic isolates; assay-specific.
Boujhoud et al. (2025)	<i>Osmundea pinnatifida</i> Sidi Bouzid, El Jadida	Polysaccharide-rich preparation	Pro-angiogenic; animal wound healing	Pro-angiogenic and wound-healing responses.
Sabir et al. (2025)	<i>Cystoseira baccata</i> , <i>C. mediterranea</i> , <i>C. myriophylloides</i> , Sidi Bouzid	Hot-water crude polysaccharides	DPPH; ABTS; reducing power; other chemical assays	DPPH IC50: 2.033, 0.620 and 0.306 mg/mL, respectively; not cellular antioxidant proof.
Belmouden et al. (2025)	Four brown macroalgae Moroccan collection	Ethanol	<i>Meloidogyne spp.</i>	Nematicidal activity under laboratory conditions.
Benhniya et al. (2025)	<i>Plocamium cartilagineum</i> Moroccan coast	Polysaccharide PCPS	HSV-1; inflammation-related assays; CAM	HSV-1 EC50 3.84 ± 2.8 µg/ mL; additional inflammation-related and vascular endpoints.
Ouahabi et al. (2025)	<i>Caulerpa prolifera</i> Nador lagoon	Hexane, ethyl acetate, methanol, water	Antioxidant; digestive enzymes; docking	Digestive-enzyme inhibition and antioxidant responses in vitro.
El Kaffi and Khelifi (2025)	<i>Halopitys incurvus</i> El Jadida coast	Essential oil	Antioxidant; surgical wounds in Wistar rats	Animal wound-healing proof of concept outside the polysaccharide category.
El Majnaoui et al. (2025)	<i>Gracilaria gracilis</i> ; <i>Ulva lactuca</i> , Moroccan seaweeds	Different drying treatments	Phenolics; antioxidant assays; colour	Drying treatment affected phenolic measurements, antioxidant responses and colour.
Benhniya et al. (2026a)	Seven macroalgal species El Jadida Atlantic coast	Polysaccharide fractions	Antiviral assays	Preliminary antiviral observations reported in a conference paper.
Benhniya et al. (2026b)	<i>Codium tomentosum</i> El Jadida, Morocco	Sulfated polysaccharide PSCT	HSV-1; antimicrobial; antioxidant	EC50 12.22 ± 2.90 µg/mL; CC50 >200 µg/mL in the tested model.
Brahimi et al. (2026)	<i>Ulva lactuca</i> ; <i>Sargassum muticum</i> Sidi Bouzid, El Jadida	Solvent extracts	Antioxidant; antimicrobial; UPLC–HRMS	Antioxidant and antimicrobial responses accompanied by chemical profiling.
Kabbali et al. (2026)	<i>Sargassum muticum</i> Sidi Bouzid; April/June 2022	Dietary supplementation, 10% and 20%	Cafeteria-diet obese Wistar rats	35 rats; five groups; eight weeks. Histological improvement is animal evidence.
Fayzi et al. (2026)	<i>Bifurcaria bifurcata</i> Northern Agadir coast	Hydrodistilled essential oil	GC–MS; antioxidant; antibacterial	Chemical characterization with antioxidant and antibacterial screening.

Note: DCM – dichloromethane; MeOH – methanol; CAM – chorioallantoic membrane; HSV-1 – herpes simplex virus type 1; EC50 – half-maximal effective concentration; IC50 – half-maximal inhibitory concentration; CC50 – half-maximal cytotoxic concentration; MIC – minimum inhibitory concentration; DPPH and ABTS – chemical radical-scavenging assays; FRAP – ferric reducing antioxidant power.

finding. The level of geographical detail follows the available evidence. Published taxon names are retained to preserve the link with the original experiments; selected nomenclatural equivalents are identified in the discussion. Quantitative values are reproduced only with their reported units and experimental context.

Site, season and processing: association versus causation

Collection site, season and processing can all influence the activity measured in a macroalgal preparation. Comparisons of wild and cultivated biomass and of regional collections support the importance of provenance (El-Majnaoui et al., 2023; El Majnaoui et al., 2024). Drying treatments further modify the measured response (El Majnaoui et al., 2025). Solvent comparisons show that the same biomass can yield fractions with different assay responses (Hsaine et al., 2019; Samri et al., 2019). Multiparametric screening also illustrates how preparation and endpoint affect interpretation (Grina et al., 2020). The seasonal *Artemia* study (Oumaskour et al., 2017) provides a within-study comparison across harvesting periods. However, a seasonal association does not isolate the influence of salinity, temperature or reproductive state. Comparisons between separate studies are further affected by differences in identification, maturity, storage and extraction.

Future collection programmes should record coordinates, collection date, depth or tidal level, thallus condition, reproductive state, water temperature and salinity, together with drying and storage conditions. Multi-site and multi-season designs should use independent collection batches as biological replicates. Repeated measurements on one extract estimate analytical precision and do not by themselves demonstrate seasonal reproducibility. Site selection should also reflect sustainable access to biomass rather than activity alone.

Chemical identity and assay validity

The names used in the original studies are retained in Table 1. Selected nomenclatural equivalents were checked against the World Register of Marine Species (WoRMS Editorial Board, 2026): *Gelidium sesquipedale* is treated as a synonym of *Gelidium corneum*, *Enteromorpha compressa* as *Ulva compressa*, and *Cystoseira myriophylloides* as *Cystoseira humilis* var.

myriophylloides. *Cystoseira humilis* remains an accepted name. These nomenclatural links do not retrospectively confirm specimen identity. Voucher material and, where appropriate, molecular identification are still needed to resolve ambiguous historical records.

Analytical evidence also has levels. Fourier-transform infrared spectroscopy (FTIR) supports functional-group assignments; chromatographic or mass-spectral matching can support a tentative annotation; unequivocal identification of an isolated molecule usually requires orthogonal evidence. Docking generates a mechanistic hypothesis rather than demonstrating that the proposed constituent caused the measured response. For polysaccharides, molecular-weight distribution, monosaccharide composition, linkage and sulfation data, purity and co-extracted proteins or phenolics are important for structure–activity interpretation (Benhniya et al., 2025; Sabir et al., 2025).

Chemical antioxidant assays measure reducing or radical-scavenging capacity under specified conditions. Evidence of protection in cells requires additional experiments. Coloured extracts may interfere with absorbance-based measurements, making sample blanks and complementary assays particularly useful. In antimicrobial work, inhibition-zone diameter, MIC and killing endpoints describe different properties and should be reported separately.

CONCLUSIONS

The reviewed evidence shows that bioactivity research on macroalgae harvested in Morocco spans biomedical, agricultural and aquatic applications. Antioxidant and antimicrobial screening forms the broadest evidence base, alongside more targeted enzyme, cancer-cell, antiviral, vascular and animal responses. Across the reviewed studies, biological activity is associated with defined preparations and experimental conditions, rather than with species identity alone. Collection site, harvesting season and processing contribute to this variation. The distinction between chemical screening, cellular responses and organism-level effects is therefore central to interpreting the Moroccan literature. Taken together, these findings establish the diversity of experimentally reported activities and the importance of provenance and preparation in their interpretation.

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