# ALGAE AS A SOURCE OF PHARMACEUTICAL COMPOUNDS

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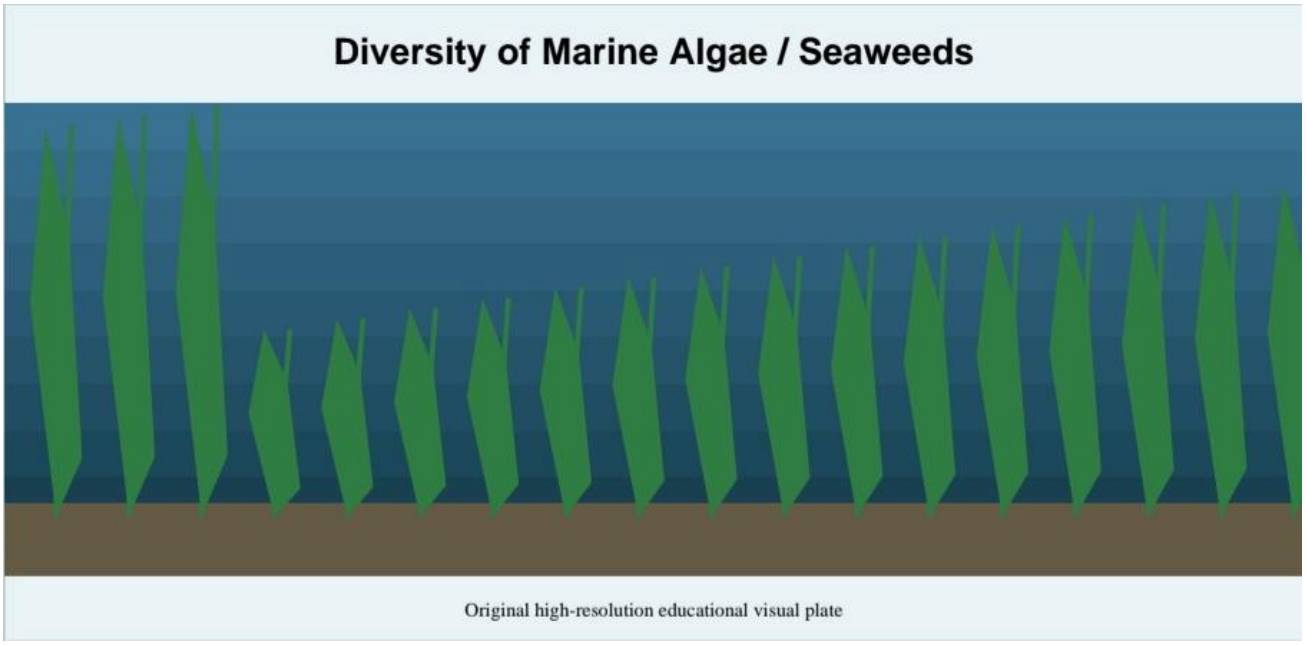
## Abstract

Algae comprise a diverse group of photosynthetic organisms that inhabit marine and freshwater environments. Their biomass contains polysaccharides, pigments, carotenoids, phenolic compounds, proteins, peptides, lipids, sterols, vitamins, and other metabolites of interest to pharmaceutical science. Some algal materials, including alginate, agar, and carrageenan, are used as functional ingredients in formulation and biomedical materials. Other constituents—such as fucoidan, fucoxanthin, astaxanthin, phlorotannin, omega-3 fatty acids, and bioactive peptides—are being investigated for antioxidant, anti-inflammatory, antimicrobial, antiviral, anticoagulant, metabolic, and anticancer activities. Their potential applications include hydrogels, wound dressings, encapsulation systems, modified drug release, topical preparations, and discovery of new therapeutic leads. However, biological activity observed in laboratory studies does not automatically demonstrate clinical effectiveness. Variations in species, growth conditions, extraction procedures, molecular structure, purity, stability, and bioavailability complicate the comparison and standardization of algal products. Contamination control, scale-up, cost, toxicological evaluation, regulatory requirements, and well-designed human studies remain important challenges. This review summarizes major algal groups and compounds, pharmaceutical roles, processing technologies, evidence limitations, and future research priorities, with emphasis on distinguishing established formulation uses from investigational therapeutic claims.

**Keywords:** algae; microalgae; seaweed; pharmaceutical excipients; alginate; fucoidan; carotenoids; drug delivery; bioactive compounds; extraction; standardization.

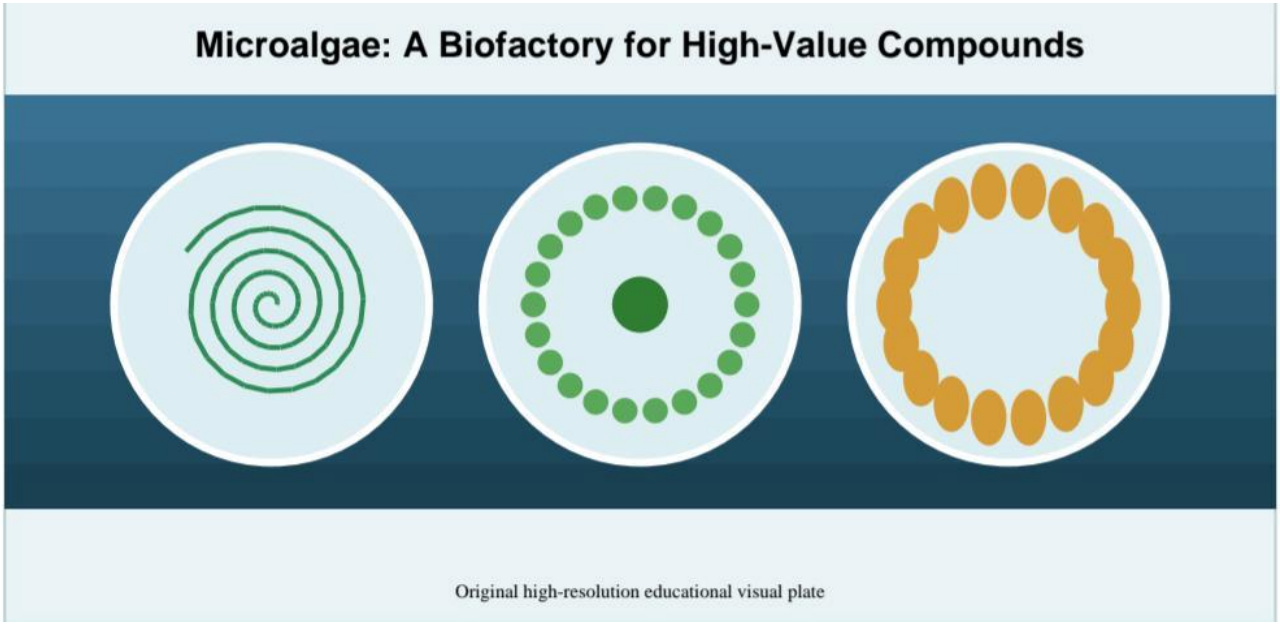
## 1. Introduction

The search for new pharmaceutical ingredients includes natural resources that offer chemical diversity and useful material properties. Algae are relevant to this search because they range from single-celled microalgae to large seaweeds and can synthesize a broad range of structural and storage molecules. Some are cultivated in controlled systems, while seaweeds may be harvested or farmed in marine environments. Their value is not limited to compounds that act directly on biological targets: algal




polymers can also modify viscosity, form gels, retain moisture, protect active ingredients, or help control drug release.

A useful distinction is required between an algal compound used as a formulation ingredient and one proposed as a medicine. Alginate, agar, and carrageenan have recognized material functions in different pharmaceutical, laboratory, food, and biomedical contexts. By contrast, many reports of anticancer, antiviral, antidiabetic, or anti-inflammatory activity for purified algal constituents are based on cell, animal, or early-stage research. The strength of evidence differs by compound, preparation, dose, route, and intended use, so broad claims about an entire species or extract should be avoided [1–4]. Different methods can be used to obtain biologically active compounds from algal biomass. The main advantage of novel extraction techniques, such as supercritical fluid extraction (SFE)-assisted extraction (MAE), ultrasound-assisted extraction (UAE), enzyme-assisted extraction (EAE), and pressurized liquid extraction (PLE) is the extraction of biologically active compounds without loss of their activity. These techniques are characterized by a higher extraction yield, a shorter process time, and finally they are more environmentally friendly than traditional extraction methods. The classical extraction techniques involve extraction in Soxhlet apparatus , solid-liquid  extraction.



## 2. Review approach and scope

The review is organized thematically around the compound classes and pharmaceutical functions described in recent review literature. The source base includes reviews on marine algae and health research, microalgae in medical applications, algal biomaterials, and fucoidan-based formulations [1–5]. The emphasis is on general principles and representative examples rather than an exhaustive inventory of every species or molecule. For a journal submission, the search strategy should be made reproducible by documenting databases, exact search strings, dates, inclusion criteria, exclusion criteria, and the number of records screened.

The text distinguishes material applications with established technical use from pharmacological effects that remain investigational. No independent laboratory results or new clinical data are claimed.

## 3. Classification and pharmaceutical relevance

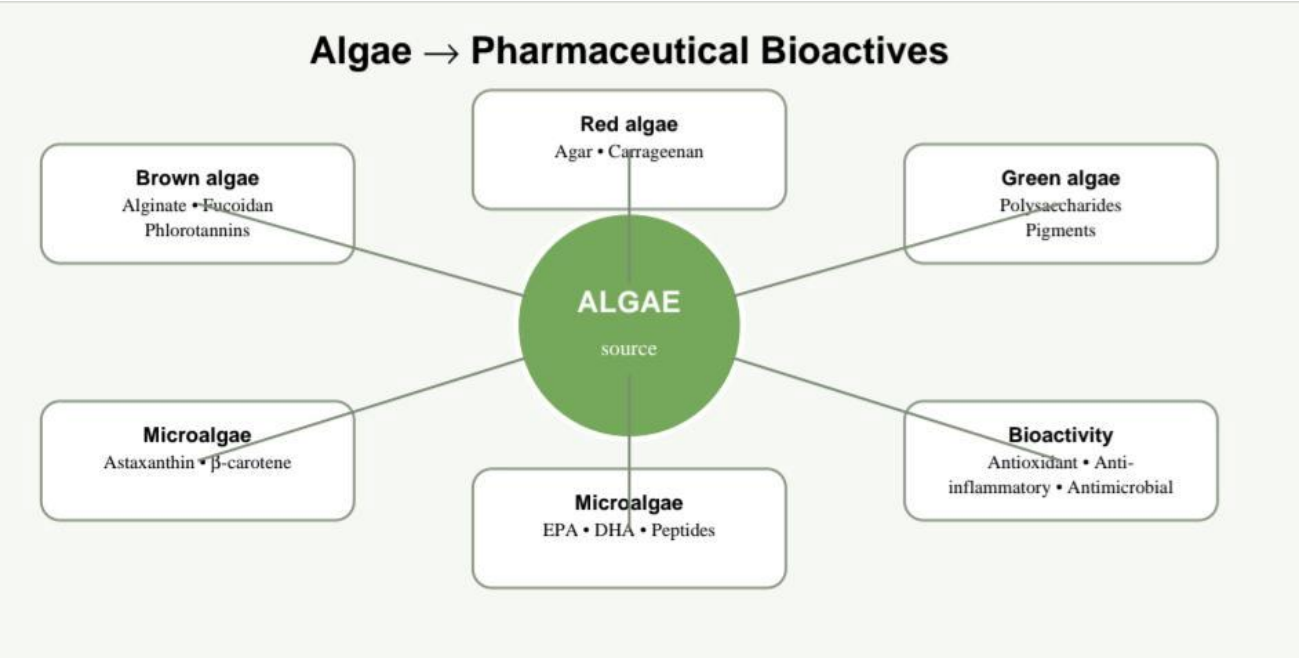
### 3.1 Microalgae

Microalgae are microscopic photosynthetic organisms that can be cultivated in ponds, tanks, or photobioreactors. Examples frequently discussed in biotechnology include Arthrospore (commonly marketed as Spirulina), Chlorella, Donatiello, and Haemapodous. Depending on the organism and cultivation conditions, they may provide proteins, pigments, carotenoids, lipids, vitamins, and peptides. Haemapodous pluvial is associated with astaxanthin production, while Donatiello salina is known as a source of beta-carotene. Microalgal systems are attractive for controlled production, but productivity depends on light, temperature, nutrients, mixing, contamination control, and downstream processing.

Macroalgae or seaweeds

Macroalgae are multicellular seaweeds commonly grouped as green, red, and brown algae. Red seaweeds are important sources of agar and carrageenan; brown seaweeds are notable sources of alginate, fucoidan, laminarin, and certain phenolic compounds; green seaweeds may provide ulvan and other polysaccharides. These broad groupings are useful for orientation, but chemical composition varies among species and can also vary with season, location, maturity, and environmental conditions.

| Group / examples | Representative compounds | Potential pharmaceutical relevance | |
|---|---|---|---|
| Microalgae: Haemapodous, Donatiello | Astaxanthin, beta-carotene, lipids | Pigment and antioxidant research; nutraceutical ingredients | |
| Microalgae: Nannochloropsis and related taxa | EPA and other lipids | Omega-3 lipid production and nutritional applications | |
| Red seaweeds: Gelidium, Gracilaria | Agar; some species yield carrageenan-related materials | Gelling, thickening, suspending and laboratory media functions | |
| Brown seaweeds: Laminaria, Macrocystis and others | Alginate, fucoidan, laminarin, phlorotannins | Hydrogels, wound-care materials, delivery research and bioactivity studies | |
| Green seaweeds | Ulvan and other polysaccharides; pigments | Biomaterial and drug-delivery research | |




## 4. Major classes of algal compounds

### 4.1 Polysaccharides and hydrocolloids

Polysaccharides are among the most useful algal products because their chain structure, charge, molecular weight, and interaction with water influence viscosity and gel formation. Alginate is a linear polysaccharide obtained mainly from brown seaweeds. In the presence of suitable multivalent ions, alginate can form gels, making it useful in beads, hydrogels, encapsulation, and wound-care materials. Its performance depends on polymer composition, molecular weight, cross-linking conditions, and formulation design.

Agar, obtained from selected red seaweeds, forms gels and is widely recognized for laboratory culture media and technical applications. Carrageenans are sulfated polysaccharides from red seaweeds; their thickening and gelling behavior depends on carrageenan type, ions, concentration, and temperature. These materials can serve as excipients or matrix components, but grade, purity, compatibility, and intended route of administration must be considered before pharmaceutical use.

Fucoidan is a variable family of sulfated polysaccharides commonly associated with brown algae. Research has explored its immunomodulatory, antiviral, anticoagulant, and anticancer potential, as well as its use in drug-delivery systems. Its composition is not uniform: source species, extraction method, molecular weight, sulfate content, and structural features can substantially affect activity. Therefore, results from one fucoidan preparation cannot automatically be generalized to all fucoidans [3].

Laminarin and ulvan are additional polysaccharides of research interest. Their potential biological or material functions require characterization of the specific preparation. For all algal polymers, batch-to-batch consistency is essential if they are to be used in reproducible dosage forms.

### 4.2 Carotenoids and pigments

Astaxanthin is a xanthophyll carotenoid associated with Haematococcus pluvial is and is investigated for antioxidant and anti-inflammatory effects. Beta-carotene, produced by organisms including Dunaliella salina, can act as a precursor of vitamin A. Fucoxanthin is a characteristic pigment in many brown algae and diatoms and is studied for

possible antioxidant, inflammatory, and metabolic effects. Pigments such as chlorophylls and phycobiliproteins are also of interest for analytical, nutritional, and biotechnology applications.

Carotenoids can be sensitive to oxygen, light, heat, and unsuitable storage conditions. Their low water solubility may complicate formulation and absorption. Encapsulation, emulsions, lipid carriers, and protective packaging are therefore investigated to improve stability and delivery. Claims of disease prevention or treatment should be supported by human evidence and must not be inferred from antioxidant tests alone.

### 4.3 Phenolic compounds and phlorotannins

Phlorotannins are polyphenolic compounds particularly associated with brown algae. Laboratory studies have examined antioxidant, antimicrobial, and anti-inflammatory effects. Their measured activity may depend on extraction solvent, degree of polymerization, assay conditions, and co-extracted compounds. Chemical characterization is needed to distinguish a defined substance from a complex extract. Potential uses include lead discovery and investigation as functional ingredients, but clinical efficacy and suitable doses require further study.

### 4.4 Proteins, peptides, and phycobiliproteins

Algal proteins may contribute nutritional value and can be processed to release smaller peptides. Some peptides have been investigated for antioxidant, antihypertensive, antimicrobial, or immunomodulatory activity. Phycobiliproteins are light-harvesting proteins found in certain algae and cyanobacteria and have applications in research, diagnostics, and pigment-related technologies. For pharmaceutical development, researchers must evaluate purity, sequence or composition, stability during digestion, immune reactions, and the feasibility of producing consistent batches.

### 4.5 Lipids, fatty acids, and sterols

Certain microalgae are sources of long-chain omega-3 fatty acids, including eicosapentaenoic acid (EPA) and, in some production systems, docosahexaenoic acid (DHA). These lipids are relevant to nutrition and are studied in relation to cardiovascular and other health outcomes. Algal production can provide an alternative source to fish-derived oils, although composition and yield depend on the organism and process. Oxidation is an important quality concern and may require oxygen-limiting packaging and appropriate antioxidants.

Sterols, including fucosterol reported in brown algae, are being investigated for biological effects. As with other natural products, findings from isolated compounds or laboratory models should be treated as preliminary until adequate pharmacokinetic, toxicological, and clinical evidence is available.

## 5. Representative compounds and applications

| Compound / class | Representative source | Main formulation or research interest | Evidence caution |
|---|---|---|---|
| Alginate | Brown seaweeds | Hydrogels, beads, wound dressings, encapsulation and controlled release | Performance depends on grade and cross-linking |
| Agar | Selected red seaweeds | Gelling agent and microbiological culture media | Use depends on quality and intended application |

| Carrageenan | Red seaweeds | Thickening, gelling, suspension and matrix systems | Type and grade matter; suitability is route-specific |
|---|---|---|---|
| Compound / class | Representative source | Main formulation or research interest | Evidence caution |
| Fucoidan | Brown algae | Drug-carrier research and biological activity studies | Heterogeneous structure; clinical evidence is limited |
| Astaxanthin | Haematococcus pluvial is | Antioxidant/nutraceutical research | Stability and bioavailability require attention |
| Beta-carotene | Dunaliella salina and others | Pigment and vitamin-A precursor | Dose and safety context matter |
| Fucoxanthin | Brown algae and diatoms | Metabolic and anti-inflammatory research | Many findings remain preclinical |
| Phlorotannins | Brown algae | Antioxidant and antimicrobial lead research | Extract composition can vary |
| EPA / DHA | Selected microalgae | Omega-3 lipid ingredients | Oxidation and composition must be controlled |
| Bioactive peptides | Microalgae and seaweeds | Antihypertensive, antioxidant and antimicrobial research | Digestive stability and clinical relevance need validation |

## 6.Pharmacological activities: evidence and interpretation

### 5.1 Antioxidant and anti-inflammatory potential

Several algal pigments and phenolic compounds are studied in assays that measure radical scavenging or oxidative damage. Fucoxanthin, astaxanthin, beta-carotene, and phlorotannins are common examples. Some experimental studies also examine inflammatory mediators and signalling pathways. Such assays can help identify candidates for further study, but they do not by themselves establish prevention or treatment of disease in people. The concentration used in a laboratory experiment may not be achievable after oral administration, and the compound may be metabolized before reaching the relevant tissue.

### 5.2 Antimicrobial and antiviral research

Algal extracts, fatty acids, phenolics, peptides, and sulphated polysaccharides have been tested against selected microorganisms or viral systems. Proposed mechanisms may include effects on microbial membranes, enzymes, adhesion, or viral attachment and entry. Results depend on the test organism, concentration, extract composition, and experimental model. Before therapeutic claims can be made, activity must be confirmed using standardized assays, selectivity testing, toxicity studies, and appropriate clinical evaluation.

### 5.3 Anticoagulant and cardiovascular-related research

Some sulfated polysaccharides, including certain fucoidan preparations, have been investigated for effects on coagulation. The same property that attracts interest can also create a safety concern, particularly for people taking anticoagulant or antiplatelet medicines. Chemical variation makes it difficult to predict the magnitude of an effect from the name of the compound alone. Products intended for systemic use require careful assessment of dose, bleeding risk, interactions, and pharmacokinetics.

### 5.4 Metabolic and anticancer research

Fucoxanthin, astaxanthin, phlorotannins, peptides, and other algal constituents have been explored in cell and animal models related to glucose and lipid metabolism or cancer biology. Reported outcomes may involve cell signaling, oxidative stress, inflammation, cell-cycle regulation, or apoptosis. These mechanisms are useful for generating hypotheses, not proof that an algal product is an effective cancer or diabetes treatment. Clinical trials must establish clinically meaningful outcomes, dose, safety, and comparative benefit.

### 5.5 Summary of evidence levels

| Evidence level | What it can show | What it cannot establish alone |
|---|---|---|
| Chemical / in-vitro assay | A measurable property under defined test conditions | Human benefit, safe dose, or effectiveness in the body |
| Cell-based study | Effects on cells and possible mechanisms | Whole-body exposure, organ safety, or clinical efficacy |
| Animal study | Biological effects in a living model | Equivalent response in humans |
| Early clinical study | Initial human safety or preliminary signals | Definitive effectiveness or uncommon adverse effects |

## 6.Pharmaceutical formulation and drug-delivery applications

### 5.6 Hydrogels, beads, and microspheres

Alginate-based hydrogels can entrap drugs, cells, or other materials within a hydrated polymer network. Gel beads and microspheres are studied for protection of sensitive ingredients, localized delivery, and modified release. Release behavior is affected by polymer concentration, cross-link density, pH, ionic strength, drug solubility, and geometry. A formulation should be evaluated for loading efficiency, drug-content uniformity, swelling, mechanical strength, release kinetics, and stability.

### 5.7 Wound-care and tissue-engineering materials

Moisture-retaining alginate dressings are used in wound-care contexts because the material can interact with wound fluid and form a gel-like layer. Other algal polymers are being investigated as scaffolds or components of tissue-engineering materials. Biocompatibility is not a single universal property: it must be evaluated for the specific material, impurity profile, degradation products, contact duration, and intended site of use. Sterilization may also alter polymer structure or mechanical performance.

### 5.8 Oral and modified-release systems

Algal polymers can be incorporated into tablets, beads, capsules, or matrix systems to alter hydration, disintegration, diffusion, and drug release. A polymer may slow release in one formulation and behave differently in another because the outcome depends on the drug and the surrounding formulation. Studies should compare release profiles with appropriate controls and examine whether the system remains reproducible across batches.

### 5.9 Topical, mucosal, and advanced delivery systems

Hydrogels and polymeric films containing algal materials are being explored for topical and mucosal delivery. Fucoidan has also been reviewed as a component in oral, topical, inhalable, injectable, and other advanced formulation concepts, but these are not all established clinical products [3]. Route-specific testing is essential because the requirements for an injectable product differ greatly from those for a topical gel or oral excipient. Sterility, endotoxin, particulate matter, osmolality, irritation, and systemic exposure may be relevant depending on the route.

### 5.10 Nanocarriers and combination systems

Algal polymers and extracts may be investigated in nanoparticles, emulsions, liposomes, and other carrier systems to improve dispersion, protect unstable molecules, or modify release. Such systems can introduce additional complexity: particle size distribution, surface properties, encapsulation efficiency, drug leakage, storage stability, and scale-up reproducibility all need to be characterized. The use of a natural polymer does not automatically make a nanocarrier safe, biodegradable in every setting, or clinically superior.

## 6. Cultivation, extraction, and downstream processing

A typical process begins with selection and authentication of the organism, followed by cultivation or responsible harvesting. Biomass is then collected, washed where appropriate, stabilized or dried, and processed to release the desired constituent. Extraction is followed by clarification, fractionation or purification, chemical characterization, and quality testing. The sequence depends on whether the target is a pigment, lipid, polysaccharide, protein, or peptide.

| Process stage | Purpose | Important controls |
|---|---|---|
| Strain/species selection | Choose a suitable and authenticated biological source | Identity, contamination, growth performance |
| Cultivation or harvesting | Produce biomass under defined conditions | Light, temperature, nutrients, salinity, season and traceability |
| Harvesting and stabilization | Collect biomass and limit degradation | Moisture, oxidation, microbial quality and storage |
| Cell disruption / extraction | Release the target compound | Solvent, pH, temperature, time, energy input and yield |
| Separation / purification | Remove debris and unwanted co-extractives | Purity, residual solvents, salts and process residues |
| Characterization | Confirm identity and key structural properties | Chromatography, spectroscopy, molecular weight or compositional tests |
| Standardization / final testing | Ensure suitability of the ingredient or product | Potency, microbial limits, contaminants, stability and batch consistency |

### 6.1 Conventional extraction

Conventional methods may include water extraction, solvent extraction, acid or alkaline treatment for selected materials, and filtration or precipitation. The appropriate method depends on the chemical class. Harsh conditions can degrade pigments, denature proteins, alter polysaccharide molecular weight, or co-extract unwanted substances. Therefore, maximum yield is not necessarily equivalent to maximum quality or biological activity.

### 6.2 Emerging and lower-solvent methods

Ultrasound-assisted, microwave-assisted, enzyme-assisted, and membrane-based techniques are investigated to improve mass transfer, shorten processing time, or reduce solvent use. These approaches should be compared with conventional methods using measurable criteria such as recovery, purity, energy consumption, solvent demand, product integrity, and cost. A method should not be called sustainable solely because it is described as green; a broader assessment of energy, water, waste, and scale-up is needed.

### 6.3 Characterization and analytical tools

Analytical methods help confirm identity, purity, and consistency. Depending on the compound, suitable tools may include UV-visible spectroscopy, infrared spectroscopy, high-performance liquid chromatography, gas chromatography, mass spectrometry, nuclear magnetic resonance, electrophoresis, and molecular-weight analysis. No single method is sufficient for every class of algal product. Validated methods and reference standards are important when results are used for specifications or batch release.

## 7. Quality control, safety, and regulatory considerations

Algal composition may vary because of species, geography, season, cultivation conditions, harvest time, and processing. A pharmaceutical ingredient therefore needs a defined identity, specification, and reproducible manufacturing process. Relevant quality attributes may include active-compound content, molecular-weight distribution, degree of sulfation, viscosity, gel strength, moisture, residual solvents, microbial limits, and stability.

Marine and freshwater biomass can accumulate unwanted substances from the environment. Depending on the source and production system, testing may be needed for heavy metals, microbial contamination, marine toxins, pesticides, residual solvents, and other impurities. Some cyanobacteria, often casually grouped with microalgae in commercial contexts, can produce toxins; source authentication and suitable screening are important. Products should not be assumed safe merely because they are natural.

Safety assessment must match the intended route and exposure. Oral, topical, inhaled, and injectable products have different requirements. Potential interactions also deserve attention, especially where a compound is investigated for anticoagulant or metabolic effects. Claims about treating disease should be supported by appropriate evidence and comply with applicable regulatory standards. Requirements differ by country and by whether a product is regulated as a medicine, excipient, medical device, food, or supplement.

## 8. Advantages and limitations

### 8.1 Advantages

- Algae provide a broad range of chemical classes and useful polymer properties.
- Many microalgae can be cultivated under controlled conditions, supporting process development and traceability.

- Some algal materials are suitable for hydrogels, encapsulation, and other biomaterial applications.
- Integrated biorefinery approaches may recover more than one valuable fraction from the same biomass.
- Algal cultivation and processing offer opportunities for biotechnology, strain improvement, and lower-solventmanufacturing.

### 8.2 Limitations and challenges

- Composition can vary by species, strain, environment, season, and processing conditions.
- Purification and analytical characterization may be costly, especially for high-purity products.
- Some bioactive compounds have low solubility, limited stability, poor absorption, or rapid metabolism.
- Environmental contamination and biological toxins require risk-based screening and control.
- Preclinical activity is often more extensive than high-quality human clinical evidence.
- Scale-up, consistent supply, regulatory classification, and commercial cost can limit translation.

## 9. Future prospects and research priorities

Future development will depend on linking biological discovery with reproducible manufacturing and clinically relevant evaluation. Strain selection, controlled cultivation, metabolic engineering, and biorefinery strategies may improve yield or enable more consistent production. The use of multiple fractions from one biomass source could improve resource efficiency, provided that each fraction can meet its own quality and safety requirements.

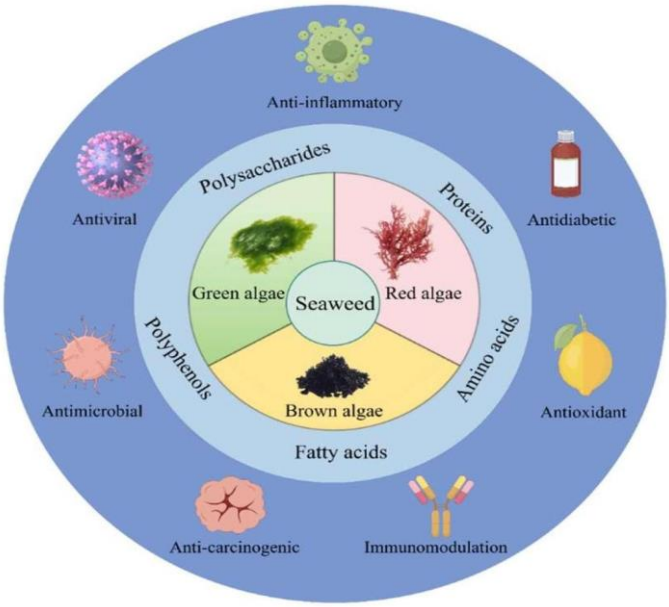
For therapeutic leads, studies should establish a clear chemical identity, mechanism-related evidence, dose-response relationships, pharmacokinetics, toxicity, and interactions before progressing to clinical trials. For formulation materials, priorities include robust specifications, compatibility studies, long-term stability, sterilization compatibility where relevant, and performance under realistic storage and use conditions. Researchers should report negative findings and compare results using standardized analytical methods.

A further priority is to distinguish the effects of purified molecules from those of crude extracts or whole biomass. Without this distinction, it is difficult to reproduce results or identify the constituent responsible for a biological effect. Well-designed clinical studies should use a defined product, appropriate comparator, justified endpoints, transparent reporting, and adequate safety monitoring.

## 10. Biological uses

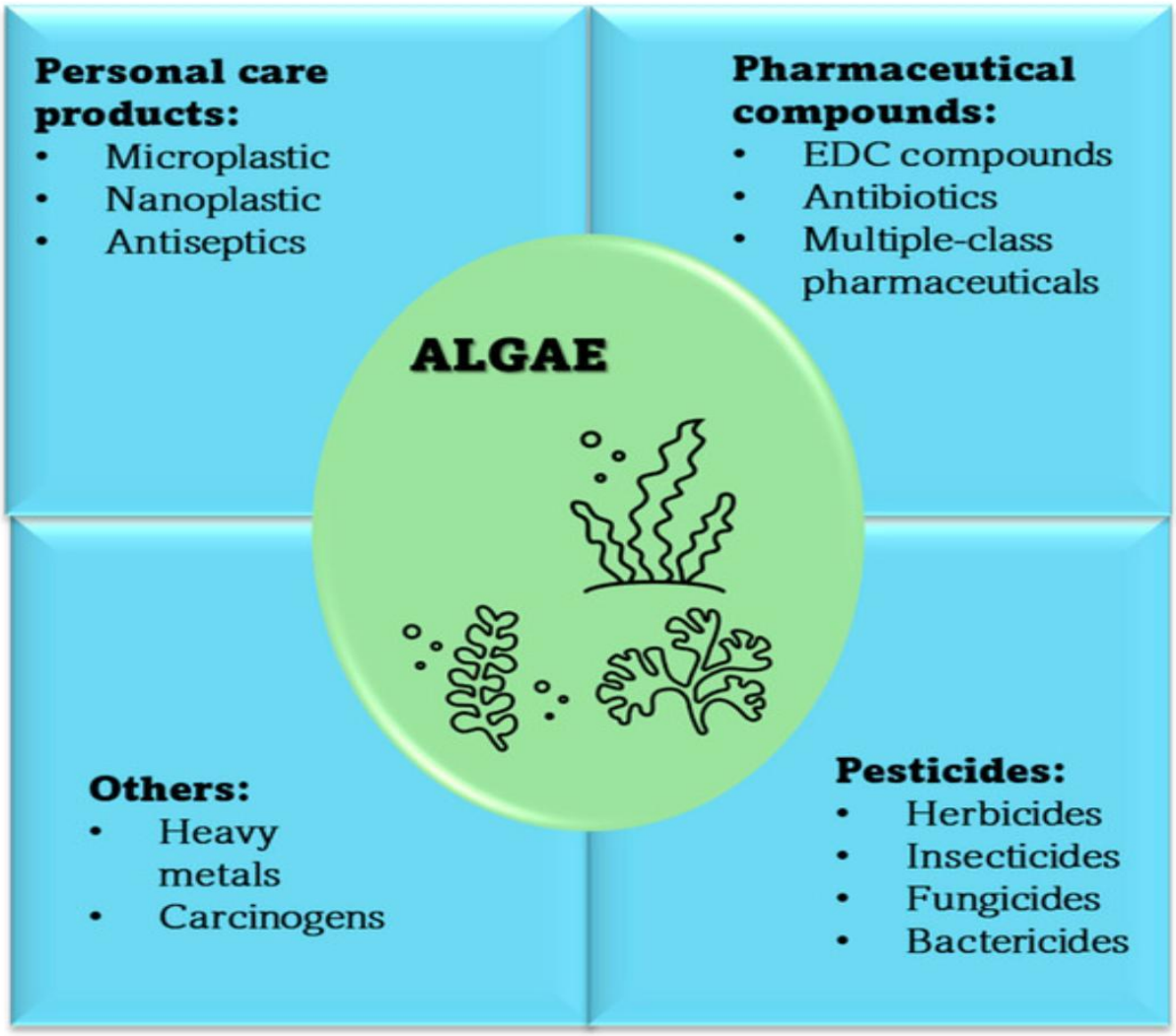
1. Nutritional uses: Algae such as Spirulina and Chlorella are rich in proteins, vitamins, minerals and essential nutrients**.**
2. Medicinal uses: Algae contain bioactive compounds with antioxidant, anti-inflammatory, antimicrobial and other potential therapeutic properties.
3. Pharmaceutical uses: Agar, alginates and carrageenan are used as pharmaceutical excipients in tablets, capsules, gels and suspensions.
4. Laxative use: Agar acts as a bulk-forming laxative and helps relieve constipation.
5. Antioxidant activity: Algae contain compounds such as carotenoids and polyphenols that help protect cells from oxidative damage.

6. Antimicrobial activity: Certain algal extracts show activity against some bacteria and fungi.




7. Industrial uses: Agar is used as a culture medium in microbiology, while alginates and carrageenan are used as thickening and stabilizing agents.

8. Environmental uses: Algae absorb carbon dioxide and help produce oxygen. Some species are also used in wastewater treatment.

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## 11. Conclusion

Algae are versatile biological resources for pharmaceutical science because they provide both functional materials and compounds that can serve as leads for further research. Alginate, agar, and carrageenan are especially relevant for their formulation and material properties, while fucoidan, carotenoids, phlorotannins, peptides, omega-3 fatty acids, and sterols attract interest for a range of biological activities. Their potential applications include hydrogels, wound-care materials, encapsulation, modified drug release, topical systems, and discovery research.

The field should nevertheless be evaluated with scientific caution. Activity in a test tube or animal model does not establish clinical benefit, and the word 'natural' does not guarantee safety. Reliable pharmaceutical development requires authenticated sources, validated extraction and analytical methods, standardized composition, contaminant control, route-specific safety assessment, regulatory compliance, and human evidence where therapeutic claims are made. These steps will determine which algal discoveries can be translated into reproducible and useful healthcare products.

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