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Pharmacognostic Investigation of Marine Seaweed

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ABSTRACT

Marine seaweeds represent a diverse group of organisms with remarkable nutritional, pharmacognostic, and phytopharmacological potential. Broadly classified into red, green, and brown algae, each group exhibits distinct morphological, biological, and chemical characteristics that contribute to the production of unique bioactive compounds. These include antioxidants, anti-inflammatory agents, polysaccharides, proteins, and secondary metabolites that have demonstrated wide-ranging health benefits and therapeutic applications. In recent years, seaweeds have gained increasing recognition as valuable resources for pharmaceutical and cosmeceutical development owing to their ability to provide natural, safe, and sustainable alternatives to synthetic drugs. The document further emphasizes methods of seaweed collection, extraction, and analysis, highlighting both traditional and modern techniques. Special focus is placed on the importance of sustainable harvesting practices and the use of advanced extraction technologies to ensure reproducibility, efficiency, and preservation of bioactive integrity. Such approaches are critical for developing high-quality products that meet industrial and clinical standards. In conclusion, marine seaweeds are emerging as an indispensable natural resource with immense promise for the biomedical field. While significant progress has been made in characterizing their bioactive constituents, further interdisciplinary research is necessary to fully harness their pharmacological potential and translate them into safe, effective, and commercially viable therapeutic agents.

Keywords: Algae, Gracilaria Corticata, Marine Seaweed, Sargassum Wightii, Ulva Lactuca.

1.MARINE RESOURCES AND ECOLOGICAL IMPORTANCE OF SEAWEED

1.1. INTRODUCTION

Oceans and seas constitute more than 70% of planet Earth, representing the largest habitat on Earth [1]. Natural products (NPs) from marine have played a central role in drug discovery. The first marine natural products (NPs) that had a clear impact on drug development for humans were the arabino-nucleosides spongothymidine and spongouridine. This research led to two important drugs: **Cytarabine** (ara-C), used to treat leukemia, **Vidarabine** (ara-A), used as an antiviral. The first drug directly derived from a marine NP approved by the FDA was **Ziconotide** in 2004, Ziconotide blocks a calcium channel, used to treat severe and chronic pain, especially in patients who do not respond to other painkillers.[2]

Marine organisms (algae, bacteria, molluscs, soft corals and sponges) produce chemical compounds with beneficial medical and industrial uses. These chemicals and natural products can be developed as pharmaceuticals, nutritional supplements, medical diagnostics, cosmetics, agricultural chemicals (pesticides and herbicides), enzymes and chemical probes for disease research, and for many other applications" [3]. Marine algae become very good sources of bioactive compounds such as dietary fiber, omega-3 fatty acids, carotenoids, vitamins, and minerals [4]. Algae do not have roots, leaves, stems or vascular systems. Algae reproduction can be sexual or asexual. Algae appear in different cellular forms (a single microscopic cell, macroscopic multicellular clusters, branched or more complex leaf or blade forms), which contrasts with the homogeneity of vascular plants. [1]

Fig:1 Seaweed

Algae are heterogeneous group ,two major types of algae can be identified: the macro algae (seaweeds) occupy the littoral zone, which included green algae, brown algae and red algae, and the micro algae are found in both benthic and littoral habitats and also throughout the ocean waters as phytoplankton .Phytoplankton comprises organisms such as diatoms , dinoflagellates, green and yellow flagellates, blue green algae.[5] Seaweeds, (fig 1) as a broad group of multicellular marine algae, encompass a wide range of species that inhabit marine environments worldwide. They exhibit a remarkable array of shapes, sizes, and colors, contributing to the visual richness and ecological importance of coastal ecosystems. [6]

1.2. HISTORY OF MARINE ALGAE (SEA WEED)

- **1945: Spongothymidine** discovered from marine sponge — first biologically active marine natural product, initiating marine drug research.

- **1960s**: Systematic efforts began to extract drugs from the sea, driven by rising interest in novel bioresources.

- **1970s**: Foundational studies in marine chemistry and pharmacology began, laying the groundwork for marine-derived therapeutics.

- **Ziconotide**: The first marine-derived drug, a peptide from cone snail venom, was approved by the U.S. FDA as Prialt for chronic spinal pain.

- **2007**: Trabectedin (Yondelis/ET-743) from sea squirt was approved in the EU for soft tissue sarcoma treatment.

- **Today**: Over 39,500 marine natural products identified, many with potent biological activities including anticancer, antiviral, and anti-inflammatory effects.

Seaweeds, as marine macroalgae, have long been used in traditional medicine across Asia and are now a major focus in modern pharmacognosy and drug development. Many marine-derived compounds, especially from seaweeds and other marine organisms, are currently undergoing Phase 1 to 3 clinical trials in the U.S. and Europe. Seaweeds offer unique bioactive compounds such as polysaccharides (fucoidan, alginate), phenolics, and phlorotannins — promising leads for anticancer, anti-inflammatory, and antidiabetic drugs. Seaweed research today is a multidisciplinary endeavor involving pharmacognosy, biotechnology, and marine pharmacology, exploring their cosmetic, nutraceutical, and pharmaceutical potential [7].

1.3. DEFINITION AND CLASSIFICATION OF MARINE ALGAE (RED, GREEN, BROWN ALGAE)

Marine algae are plant-like organisms that are typically found fixed on ocean, rock or other hard bases in coastal areas. Red and brown algae are found in marine, while green algae are also found in freshwater (rivers and lakes) and even in rocks, walls, and tree bark in damp places. The orderly systematic study of algae is called Phycology. [4]

ALGAE CLASSIFICATION

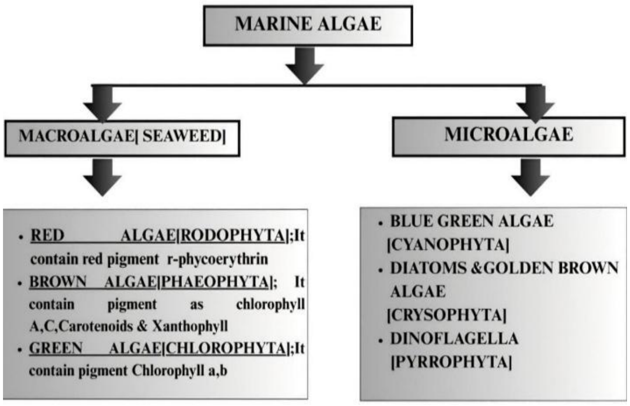
There are two main types of marine algae: Macroalgae (seaweeds) and Microalgae; -

Macroalgae [Multicellular] are large and based on their pigmentation and photosynthetic pigments again classify- Green Algae

(Chlorophyta), Red Algae (Rhodophyta), and Brown Algae (Phaeophyta).

Microalgae [Unicellular]are very small. They include Blue-Green Algae (Cyanophyta), Dinoflagellates (Pyrrophyta), Diatoms & Golden-Brown Algae (Chrysophyta).[8]

Table 1: Classification of Marine Algae



DISTRIBUTION OF MACROALGAE [SEAWEED]

GREEN ALGAE (CHLOROPHYTA):_ They are found in a wide range of marine habitats, including intertidal zones, coral reefs, and freshwater environments. Green algae [Fig 2] can exhibit varied forms, including unicellular, filamentous, sheet-like, or colonial structures.

Example of green algae with seaweed morphology include Ulva lactuca (U. lactuca, sea lettuce), and Codium tomentosum.[6]

Fig 2: Green Algae

RED ALGAE (RHODOPHYTA):_ They are commonly found in both tropical and temperate marine environments, ranging from intertidal zones to deep-sea habitats. Red algae [Fig 3] display several growth forms, including filamentous, foliose, and coralline structures. Examples of red algae include Palmariapalmata, Pyropia and coralline algae.[6]

Fig 3: Red Algae

BROWN ALGAE (OCHROPHYTA, PHAEOPHYCEAE):_ They are typically found in temperate and colder waters, including rocky shores and kelp forests. Brown algae [Fig 4] are known for their large size and complex thallus structure, which may include holdfasts, stipes, and blades. Example of brown algae include Laminaria, Saccharina (kombu), Undaria (wakame), Fucus (bladderwrack)), and Sargassum species. [6]

Fig 4: Brown Algae

2.SEAWEED COMPOSITION AND THERAPEUTIC POTENTIAL

2.1. NUTRITIONAL AND PHYTOCHEMICAL PROFILE OF SEAWEEDS

Table 2: Nutritional and Phytochemical Profile of Seaweed

PROTEIN &AMINO ACID	Protein content: 1.8 -18.9%	Maximum protein content in Phaeophyceae and minimum in Chlorophyta.	A total of 16 amino acids has been reported in seaweeds.Protein content variation among different Species of seaweed is due to the surrounding water quality.
LIPID & FATTY ACID	Lipid content; 1.5% - 5%	Chlorophyta have the highest lipid content, while Rhodophytahave the least.	Seaweeds are rich in essential fatty acids;Green seaweeds are high in α- linolenic acid & Red and brown seaweeds contain more long-chain fatty acids. Seaweeds are good sources of omega-3 and omega-6 fatty acids(prevent diseases like heart disease, arthritis, and diabetes)
CARBO HYDRATES &DIETARY FIBER	Carbohydrate content; 12%- 65%. Dietary Fiber content; 53.6-63.2%	Maximum in Chlorophyceae followed by Rhodophyceae and Phaeophycean.	Seaweeds are high in fiber, but more studies are needed to evaluate the fiber content in different seaweed species
MINERALS	Mineral content; 7–38%	Brown seaweeds contain higher amount of minerals than red seaweed.	Seaweeds are a rich source of minerals compared to terrestrial plants and have more bioavailability. The elements found in seaweeds are potassium, sodium, calcium etc.
VITAMINS	--	Phaeophyceae is rich in water -soluble vitamins such as vitamin B1, B2, B6.	Seaweeds are rich in water- soluble vitamin and commonly contain vitamins A, B12, C. ß-Carotene, pantothenate, folate, riboflavin and niacin.

2.2. BIOACTIVE COMPOUNDS [9]

Table 3: Bioactive Compounds

AGAR	Polysaccharide extracted from the red seaweeds. Mixture of Agarose and agaropectin.	Agar-Agar: Antitumor agent and reduces the level of blood glucose
CARRAGEENAN	Linear chain polysaccharide, extracted from red seaweed (contains up to 71% and 88%)	It is widely used due to its excellent gelling, thickening, and stabilizing properties.
ALGIN (alginic acid)	Natural polysaccharide found in the cell walls of brown seaweeds	It has many industrial and health-related uses due to its thickening, gelling, and stabilizing properties
MANNITOL	It was first extracted from brown seaweed.The amount of mannitol is lower in green and red Seaweeds	Carbohydrate storage, Osmo Regulation
FUCOIDAN	Sulphated polysaccharide is	Anti-cancer, Anti-inflammation,

	extracted from brown seaweeds.	Antiviral etc
LAMINARAN	Storage polysaccharide (a type of β-glucan) found in brown Seaweed	Antitumor properties,Anti-apoptotic effects, Immunomodulatory effects
CAROTENOIDS	Tetraterpenoid pigments found in seaweeds.They help in classifying seaweeds as red, green, or brown	Primary Carotenoids;Help in photosynthesis Eg;α-carotene, βcarotene, Violaxanthin, Neoxanthin, Fucoxanthin , Zeaxanthin, Lutein. Secondary Carotenoids; Produced under stress or special conditions (extra pigments) :Eg;Astaxanthin,Canthaxanthin,Echinenone.

2.3. THE ROLE OF MARINE ALGAE IN MODERN PHARMACOGNOSY AND DRUG DISCOVERY

Marine algae or seaweeds (Ochrophyta, Rhodophyta, and Chlorophyta) are valuable in food, cosmetics, medicine, and health supplements. They help treat various diseases and contain natural compounds with antioxidant, antimicrobial, and antiviral properties. Seaweeds are non- toxic, edible, affordable, and easy to grow, making them a natural alternative to synthetic chemicals [10] Marine drugs come in many forms, have unique structures, and work in different ways. They show great promise for treating various diseases like cancer, diabetes, heart problems, and neurodegenerative disorders. [11]

Algae are affordable and widely used in food, animal feed, fish farming, and fertilizers. They are rich in carbohydrates, fats, proteins, vitamins (A, B, C, E), and minerals like iron, potassium, calcium, magnesium, manganese, and zinc. People in countries such as Japan, China, Ireland, and the U.S. have used algae in food for centuries.

Although seaweed compounds have great potential in drug discovery, challenges remain. These include identifying the right active compounds, improving extraction methods, ensuring large- scale and eco-friendly farming, and studying their effects and safety. Scientists are now using advanced tools like genomics and metabolomics to explore seaweed chemistry and find new medicines. [6]. Seaweed, or large marine algae, is important for the environment and widely used in food, cosmetics, and industry. Recent research shows it also contains natural compounds with healing properties. Since oceans cover most of the Earth and hold many organisms like seaweed they are a rich source for discovering new medicines. New drugs are needed to treat diseases like cancer, infections, and brain disorders. Current treatments have limits, so finding new sources is important [6].

Seaweeds have special compounds that help them survive in tough ocean conditions, which could be used to create new and better medicines AI is rapidly advancing, and new technologies like quantum computing, federated learning, and reinforcement learning are poised to transform drug discovery. [13]

2.4. PLANT PROFILE [14]

Table 4: Plant profile of marine seaweed

PLANT NAME	**RED ALGAE**	**GREEN ALGAE**	**BROWN ALGAE**
SPECIES	Gracilaria corticate	Ulva lactuca	Sargassum wightii
SYNONYM	Sphaerococcus Corticates	Ulva fasciata Delile, Ulva crassa Kjellman	Sargassum bacciferum, gulfweed, Sargasso.
TAXONOMY	**Division**: Rhodophyta **Class**: Florideophyceae **Order**: Gracilariales **Family**: Gracilariaceae	**Division**: Chlorophyta **Class**: Ulvophyceae **Order**: Ulvales **Family**: Ulvaceae	**Division:** Ochrophyta **Class:** Phaeophyceae **Order:** Fucales **Family**: Sargassaceae
DISTRIBUTION	In India, Trichendeur, Pudumadam, Cape Comorian, Mandapam, Dwaraka, Bombay	Indian Ocean, Trivandrum (Kerala), Cape Comorian (Tamil Nadu),	Andaman Island, Pudumadam, Mandapam, Kerala, Karnataka, Maharashtra.
TRADITIONAL USES	Intestinal constipation, enteritis, dysentery,urinary disorders , thyroid diseases, Demulcent [15]	Anti-inflammatory, ACE inhibitor, Antioxidant, Ion flow regulatory role [16]	Anticancer, antibacterial, antifungal, antiviral, Anti-inflammatory, neuroprotective activities [17]

RED ALGAE-GRACILARIA CORTICATA

In China, some species of **Gracilaria** are indictated in the treatment of intestinal constipation, enteritis, dysentery, urinary disorders, thyroid diseases, and respiratory disease. In India, used as an emollient and demulcent in treatments of respiratory diseases, diarrhea, and dysentery.

Fig 5: Gracilaria corticate

Macroscopic characteristics.

- Thalli -dark red to purple colour, flattened fronds, 10-18 cm in height, rigid and cartilaginous.
- Apices of branches acute-margin of the thallus smooth or sometimes with proliferations.
- Cortex- 1-2 layered, outer layer of narrowly elongated cells, 6-9 um long and 3-6um broad and the inner of radially compressed, slightly larger cells. Medullary regions with large thick-walled cells measure 118-160 um broad and 180-220 um long.
- Cystocarps hemispherical occurs on the surface of thalli, 0.8-1.4 mm wide. [14]

Microscopic characteristics.

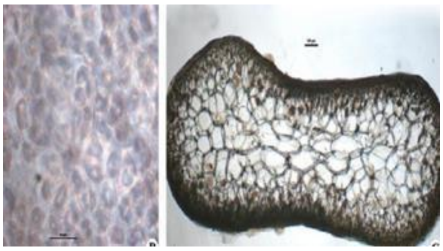


Fig 6: Microscopy of Gracilaria corticate

Gracilaria corticate is an erect red alga reaching up to 14 cm tall, growing from a discoid holdfast with a short, often inconspicuous stipe (up to 5 mm). It branches frequently, mainly dichotomously, becoming dense towards the upper regions. Blades are linear, with smooth surfaces and margins, and usually have obtuse apices. The texture is cartilaginous, and fresh specimens range from purple to green, turning black to green when dried. Large galls or tumorous swellings often occur on mature blades.[18]

GREEN ALGAE-ULVA LACTUCA

Anti-inflammatory compounds have been isolated from green algae like **Ulva Lactuca** and **Cladophora fascicularis**. In Okinawa, research for alternatives to snake venom serum led to the discovery of diphenyl ethers from algae, which showed anti-inflammatory and antibacterial effects.[19]

Fig 7: Ulva Lactuca

Macroscopic characteristics

- Thalli attached to the substratum by small circular disc.

- Lamina up to 40 cm, sometimes longer, up to 1 Meter, 10-14 cm wide, deeply divided into several more or less distinct, Linear lobes, 1-3 cm wide, frequently with undulate margins, 110-115 um in thickness in basal portions and 70-90 um in upper portions.

- Cells in Surface view polygonal, uniformly About 20 pm across; in section, Palisade like, 40ums in height and 9.9-16 pm broad, 9 pm apart, Enclosed within a cuticle 3.2 pm Thick.[14]

Microscopic characteristics

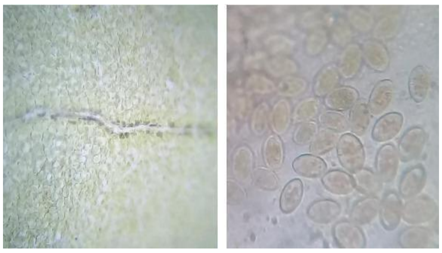


Fig 8: T.S of Thallus

Ulva Lactuca has a thin, two-cell-layered, sheet-like thallus with regional variation:

- **Lower basal region**: Rounded cells in pairs or rows; dark, large rhizoidal cells form attachment ribs; no central cavity; margins have small, narrow cells (height: width = 1– 3.5). Chloroplasts cover the outer wall, often tilted, with 1–3 pyrenoids (~5 µm).

- **Upper basal region**: Irregular 3–6-sided cells in small groups or rows; thicker cell walls; larger, less pigmented rhizoidal cells present.

- **Middle to apical regions**: Cells are sharply polygonal (4–6 sides), loosely grouped in various orientations; height: width = 1–3 (middle) and 1–2.5 (apex). Chloroplasts remain prominent and lobed with 1 (sometimes 2–3) pyrenoids (3–6 µm).[19]

BROWN ALGAE-SARGASSUM WIGHTII

In China, treating thyroid related diseases, such as simple goiter, is one of most important traditional uses for Sargassum seaweed. The iodine in Sargassum seaweed was believed to play an important role in the therapeutical function. [20]

Fig 9: Sargassum wightii

Macroscopic characteristics

- Thalli attached by basal disc Shaped holdfast.

- Main axis Cylindrical, simple, short, thick; Primary branches distichously Arranged smooth, up to 45 cm Length, flattened; secondary Branches up to 15 cm in length Flattened, arising at intervals of 3cm on the primary branches. Sterile Lateral system consists of leafy Segments upto 5 cm in length; up to 4-9 mm in breadth.

- Leaf petiolate, Linear-lanceolate, oblong, margin Subentire to entire, poorly Denticulate, sinuate dentate towards the apex.
- Leaf shows acute to Obtuse, tapering base and apex; Costae sparse, cryptostomata Scattered.
- Vesicles spherical to Elliptical, apiculate; 5-8 mm long, 4Mm broad, stalked, stalk 5-8 mm Long either leafy or very thin.
- Receptacle bisexual, Oogonial and antheridia Conceptacles distinct. [14]

Microscopic characteristics

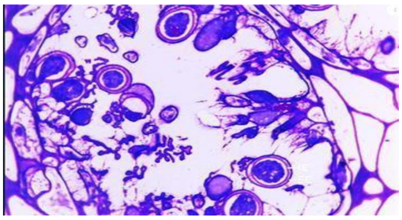


Fig. 10: Microscopy of Sargassum wightii

Leaf microscopy: The leaf-like parts were flat, broad, and thick, with no clear top or bottom side. They had a thick outer layer with a strong covering. The surface cells were tall and rectangular, all similar in size. In the middle, there was a group of small, slightly thick-walled cells called the conducting strand.

Axis (stem) microscope: Flat, spindle shaped with wider 1-2 mm thick central part having thin cuticle and less distinct epidermis, wide mesophyll. The end part was 400 µm thick, tapering and blunt. Epidermis of the stem was 20 µm thick and cuticle was dark. The inner cells were polyhedral, small, and compact. Central core cells were smaller, slightly thick walled.

Air bladder; The air bladder had wide central chamber enclosed by a thin cylinder of cells. The unsheathing cylinder had shallow ridges and furrow at certain places. The ridged portion was 250 µm thick and narrow part was 750 µm wide. The bladder has thick cuticle and district, darkly stained epidermal layer of 15-20 µm thick. The mesophyll tissue consists of 5-7 layers of tabular, compact thin-walled cells. The cells were sheathed parallel to the surface of the bladder. **Receptacles:** The receptacles were short, repeatedly branched structures. They had round cavities surrounded by one or two layers of rectangular cells. Inside these cavities, small branched structures grew, ending in swollen tips with antheridia or oogonia. The antheridial branches were club-shaped with dark spots. The oogonial branches had round tips with spherical oogonia and short, thin stalks. The chamber that held these reproductive parts eventually opened to release the gameteses. [20]

3. SEAWEED HARVESTING PROCESSING AND EXTRACTION TECHNIQUES

3.1 SOP FOR SEAWEED BIOMASS CULTIVATION AND ANALYSIS

1. HATCHERY SYSTEM REQUIREMENTS

- **Seawater Management:** Sterile, filtered, and UV-treated seawater from uncontaminated sources is used.
- **Temperature Control:** Cold-water kelp species require tightly controlled temperatures(~8–15°C).
- **Aeration and Lighting:** Continuous aeration and light cycles (including red light for vegetative growth) are used to optimize gametophyte and sporophyte development.
- **Custom Infrastructure:** Each facility (NUIG, QUB, CEVA) has tailored layouts to meet these environmental requirements.

2. GAMETOPHYTE CULTURE TECHNIQUES

- **Selection & Preparation:** Fertile sorus tissue is harvested and processed to release zoospores.

- **Culture Maintenance:** Gametophytes are grown under controlled conditions in nutrient- rich media.

- **Density Estimation:** Tools like Haemocytometers and Coulter counters are used for precise cell counting.

- **Induction Methods:** Temperature/light triggers and stress treatments induce gametogenesis and sporophyte formation.

3. SEEDING TECHNIQUES

- **Two Approaches:**

  - **Indirect Method:** Uses cultured gametophytes to generate sporophytes before seeding.

  - **Direct Method:** Involves direct release of zoospores onto twine or collectors.

- **Collector Systems:** Twine, netting, or PVC pipes serve as substrates for spore attachment.

- **Spray and Immersion Methods:** Used for uniform seeding over collector surfaces.

4. SEA-BASED CULTIVATION

- **Transport & Deployment:** Seeded materials are transferred to offshore longline systems, ensuring gentle handling to preserve young sporophytes.

- **Longline Systems:** Designed to withstand high-energy European waters, unlike the sheltered systems in Asia.

- **Monitoring & Maintenance:** Routine checks on biomass growth, fouling, and rope integrity.

5. HARVESTING PROTOCOLS

- **Selective Harvesting:** Allows for regrowth by leaving meristematic tissues intact.

- **Bulk Harvesting:** Biomass is collected using nets or manually for bioeconomy applications (e.g., food, feed, cosmetics, biofuels).

6. ENVIRONMENTAL MONITORING

- **Parameters Measured:** Temperature, Photosynthetically Active Radiation (PAR), turbidity, and nutrient levels.

- **Tools Used:** Light loggers, Niskin bottles, turbidity meters, and nutrient testing kits ensure comprehensive site profiling.

7. BIOMASS SAMPLING & ANALYSIS

- **Dry Weight Estimation:** Standardized length sampling and drying techniques determine biomass yield.

- **Morphometrics:** Frond length, width, and weight are recorded for growth analysis.

- **Preservation:** Samples are stored for future biochemical (e.g., protein, carbohydrate) analysis.

8. ANNEX: NUTRIENT MEDIA RECIPES

Recipes for enriched seawater media such as Provasoli's Enriched Seawater (PES) are included, vital for early-stage culture development.

ADDITIONAL INSIGHTS

- **Scalability:** SOPs aim to bridge the gap between lab-scale and pilot/commercial-scale kelp farming in Europe.
- **Sustainability:** Encourages environmentally sound practices (e.g., local species cultivation, effluent treatment).
- **Collaborative Research:** Data harmonization across partner facilities enables joint analysis, shared learning, and cross-validation of techniques.
- **Adaptability:** Though standardized, SOPs allow for local adaptations based on site- specific challenges or infrastructure.
- **Training Tool:** This manual also serves as a training guide for new practitioners in seaweed aquaculture.[21]

3.2. REPRODUCTION OF SEAWEED [22]

GREEN ALGAE

Green algae reproduce both sexually and asexually.

Asexual reproduction occurs through spores that can be: Flagellated (motile), or non-flagellated (non-motile). They can also reproduce by fragmentation (breaking into pieces).

Sexual reproduction can be: Isogamous (Two similar gametes fuse), Anisogamous (Both gametes have flagella but are of different sizes), Oogamous (A small flagellated male gamete fuses with a large non-motile female gamete to form a zygote.)

1. Many green algae (Chlorophyceae) are haploid, and meiosis occurs when the zygote germinates.

2. Oogamous algae have similar life cycles.

3. Some algae like Ulvalaceae and Cladophoraceae show alternation of generations with two similar phases.

4. Siphonales algae are diploid.

5. Asexual reproduction in green algae occurs by:

Zoospores (motile) or Aplanospores (non-motile).

6. Zoospores:

- Formed inside normal vegetative cells (as special sporangia are rare).
- May be produced singly or in groups.
- Are naked and have a colorless tip (beak) at the front.
- Two or four flagella arise from the beak.

7. Aplanospores:

- Found in species that usually form zoospores.
- Also found in some species that no longer form zoospores.

BROWN ALGAE

1. This group reproduces both sexually and asexually.

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2. Several species reproduce vegetatively by fragmentation.

3. Members of this group produce biflagellate neutral spores, which are found within One- celled or Many-celled reproductive organs.

4. Asexual reproduction occurs by the formation of zoospores in:

- Unilocular sporangia, or
- Pleurilocular sporangia.

5. Exceptions: Dictyotales, Tilopteridales, and Fucales do not follow this pattern.

6. Unilocular sporangia: Produce the haploid gametophytic stage.

7. Pleurilocular sporangia: Produce the diploid phase.

8. Zoospores:

- Are asymmetric or bean-shaped.
- Have two lateral or sub-apical flagella.
- Are formed in the single-celled unilocular sporangia by meiosis.
- Give rise to gametophytes.

9. Sexual reproduction can be:

- Isogamy, Anisogamy, Oogamy
- In oogamous reproduction:

1. The male sex organ is called antheridium.

2. The female sex organ is called oogonium.

3. These may be produced: On the same plant, or on different plants

Alternation of generations:

- Alternation between gametophytic and sporophytic generations occurs in this group.
- Exception: Members of Fucales do not show alternation of generations.

RED ALGAE

1. This group seldom reproduces asexually.

2. All members of this group produce one or more kinds of non-flagellated spores, which may be:Sexual in nature or Asexual in nature.

3. Sexual reproduction is very complicated, involving several structures after the fusion of gametes.

4. The male structure is called the antheridium.It produces a single spermatangium, which gives rise to non-motile spermatia.

5. The female structure is a swollen carpogonium.It usually bears a long drawn-out receptive trichogyne.

6. The zygote formation occurs either by direct division, as seen in Bangiales or after the production of filamentous outgrowth called gonimoblast, which gives rise to a number of sporangia, each forming a naked spore.

7. Reduction division may occur at the first division of the zygote nucleus or may be postponed and take place in special tetrasporangia borne on individual distinct forms.

8. Alternation of generations: Some members exhibit biphasic alternation of generations, in which the sexual generation (gametophyte) alternates with the asexual (tetrasporophyte) generation.

Other members are triphasic, with three generations or somatic phases: Gametophyte, Carposporophyte, Tetrasporophyte

These phases successively follow one another.

3.3. SEAWEED COLLECTION PROCEDURE

To systematically collect, preserve, and assess seaweed species from intertidal and subtidal zones for taxonomic, ecological, and quantitative studies.

1. IDENTIFICATION OF SEAWEED SPECIES

Based on:

1. Morphology
2. Anatomy
3. Reproductive structures
4. Cytology & ultrastructure
5. Reference herbaria or expert consultation

Difficult taxa may require molecular or chemotaxonomic methods**.**

2. INTERTIDAL SEAWEED COLLECTION

Timing: Conducted during low tide, ideally 1–2 hours before peak low tide (consult tide tables). **Site Documentation:** Record location, topography, associated flora/fauna, and ecological conditions in a field data sheet.

Essential Tools

- Polyethylene bags
- Knife/scalpel
- Labels and waterproof pens
- Rope (~50 m)
- Quadrants (0.25 m² or 1 m²)
- Field notebook
- Balance (for weighing biomass)

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Methods

A. Line/Belt Transect Method

- Lay rope perpendicular to shoreline from high tide to low tide line.
- Mark sampling points at 5–20 m intervals, depending on intertidal width.
- At each point, place the quadrant in triplicate.
- Collect all seaweed species within each quadrant.
- Record:
  - Species composition
  - Individual count per species
  - Fresh biomass

B. Random Sampling Method

- Place quadrants randomly throughout the site.
- Ensures equal probability of capturing all species.
- Best for steep gradients or patchy seaweed distributions.
- Typically used for qualitative assessment.

3. SUBTIDAL SEAWEED COLLECTION

Techniques Based on Depth

- Shallow (0.5–3 m): Snorkeling
- Deeper (up to 30 m): SCUBA diving PROCEDURE
- Use rope-marked transects with intervals (5–10 m).
- At each point, deploy a 1 m^2 quadrant.
- Collect all seaweed within each quadrant.
- Transport samples using a boat or catamaran.
- Follow same documentation and preservation as for intertidal samples.

4. SAMPLE PRESERVATION

A. Wet Preservation

- Rinse specimens to remove sand, debris, and epiphytes.
- Use 5–10% formaldehyde in seawater as preservative.

- Store samples in sealed, labeled polyethylene bags.

B. Dry Preservation (Herbarium Preparation)

- Clean specimen+s thoroughly.
- Mount on herbarium sheets in trays of water using brushes.
- Dry with cheesecloth and blotting paper in a wooden press.
- Repeat blotting until moisture-free.
- Label with:
  - Scientific name
  - Collection date and site
  - Habitat and ecological data. [22]

3.4. EXTRACTION OF MARINE CONSTITUENTS

1. Extraction Process

Marine organisms such as algae are initially subjected to drying and powdering, which enhances solvent penetration during the extraction process. The commonly employed solvents include methanol, water, and alcohol. During this stage, desalting naturally occurs, since inorganic salts generally remain insoluble in these organic solvents.

Maceration, although a traditional method of extraction, is often less preferred in the case of marine samples. This is because prolonged maceration without appropriate sterilization may lead to fungal contamination, thereby affecting the quality and yield of the extract.

2. Concentration of Extracts

Following extraction, the obtained extracts are concentrated to yield a usable form of the bioactive constituents. This is typically carried out either by evaporation at elevated temperatures or by employing vacuum flash evaporation at lower temperatures. The latter is often preferred, as it helps prevent the thermal degradation of sensitive bioactive compounds commonly present in marine organisms.

3. Desalting Techniques

Since marine organisms contain significant amounts of salts, desalting is an essential step to obtain purified extracts. Conventional membrane filtration techniques are not suitable for this purpose, as the overlap in molecular size between salts and active compounds can lead to inefficiency. Instead, gel filtration chromatography (e.g., Sephadex Biogel) is considered more appropriate. This method functions on the principle of molecular size exclusion, wherein a polymeric matrix with defined pore sizes separates molecules based on their size and gravitational flow, thereby effectively removing salts while retaining the desired bioactive constituents.

4. FORMULATION DEVELOPMENT AND THERAPEUTIC PRODUCT DESIGN

Table 5: GRACILARIA CORTICATE-BASED PRODUCTS

Brand Name	Generic Ingredients	Uses
SeaVital Capsules	Gracilaria corticate extract	Antioxidant, anti-inflammatory
NutriMarine Powder	Gracilaria + Spirulina + Antioxidants	Immune booster, skin health
HydroHeal G Gel	Gracilaria-based hydrogel	Diabetic wound healing

Table 6: ULVA LACTUCA (SEA LETTUCE)-BASED PRODUCTS

Brand Name	Generic Ingredients	Uses
Marine Green	Ulva lactuca powder + Moringa + Amla	Detox, immunity, metabolism
SeaGlow Face Pack	Ulva lactuca extract + Aloe vera	Skin rejuvenation, hydration
Algotherm Ulva Cream	Ulva extract + Marine collagen	Anti-aging skin care

Table 7: SARGASASUM WIGHTII-BASED PRODUCTS

Brand Name	Generic Ingredients	Uses	Availability
SargaThyro™ Capsules	Sargassum wightii extract + Iodine + Zinc	Thyroid stimulant, metabolism	Herbal/ayurvedic stores
Thalasso Cream	Sargassum extract + Hyaluronic acid + Marine collagen	Anti-aging, firming	65Global cosmeceutical brands
BioSea Wound Dressing	Sargassum + Chitosan (experimental/niche wound care products)	Wound healing, diabetic ulcer care	Research/clinical use
Maritech Reverse	Fucoidan from Sargassum	Cellular protection, skin repair	Australia, international

CONCLUSION

Marine seaweeds represent a promising frontier in pharmacognosy, offering a unique blend of nutritional richness and therapeutic potential. This investigation has demonstrated the extensive biological diversity and chemical complexity of marine macroalgae—particularly red (*Rhodophyta*), green (*Chlorophyta*), and brown (*Phaeophyceae*) algae—underscoring their value as sources of bioactive compounds with significant pharmacological properties. These include antioxidant, anti-inflammatory, antimicrobial, anticoagulant, and anticancer activities, driven by constituents such as polysaccharides (e.g., fucoidan, agar, carrageenan), carotenoids, phenolics, and essential fatty acids. The integration of pharmacognostic profiling, phytochemical analysis, and formulation development provides a holistic understanding of seaweeds as functional materials for pharmaceutical and cosmeceutical applications. The incorporation of standardized cultivation protocols and advanced extraction methods ensures reproducibility, quality control, and scalability for industrial use. As the demand for sustainable, bio-based solutions continues to grow, marine algae stand out as an ecologically sound and economically viable resource. Future research should prioritize the development of novel drug candidates, mechanism-of-action studies, and clinical validation, while also addressing challenges related to large-scale biomass cultivation and environmental sustainability. Ultimately, marine seaweeds hold significant potential to contribute to the next generation of natural therapeutics and health-promoting products.

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