International Journal of Research in Pharmacy and Pharmaceutical Sciences
www.pharmacyjournal.in
ISSN: 2455-698X
Received: 30-09-2025, Accepted: 29-10-2025, Published: 14-11-2025
Volume 10, Issue 4, 2025, Page No. 69-73

Exploring commercial processing of Agar-Agar from Marine Algae: An industrial visit report

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Abstract
Agar-Agar, a hydrocolloid derived from red marine algae, holds immense industrial significance in food, pharmaceutical, and biotechnological fields. This study explores the production process and commercial importance of food-grade agar-agar, emphasizing its marine sources, industrial production stages and real-world practices observed during an industrial visit. The research highlights agarophytes such as Gracilaria, Gelidium and Pterocladia as primary sources of agar extraction. Focus is also placed on the role of this marine-based industry in promoting sustainable entrepreneurship and economic development in coastal regions.

Keywords: Agar-Agar, marine algae, industrial processing, hydrocolloids, pharmacognosy, seaweed

Introduction
Marine ecosystems, covering nearly 70% of the Earth's surface, are among the richest sources of novel bioactive compounds with significant therapeutic potential. Marine organisms such as sponges, corals, algae, mollusks, and microorganisms produce secondary metabolites that serve as chemical defences in their competitive environment. These compounds have proven to be valuable in modern pharmacology, leading to the discovery of many life-saving drugs. It is estimated that more than 6,000 structurally unique and bioactive metabolites have been isolated from marine organisms, with several approved for therapeutic use, including cytarabine, trabectedin, eribulin mesylate, and brentuximab vedotin for cancer treatment [3]. Marine biotechnology continues to expand, offering immense promise for the development of new antimicrobial, anticancer, and anti-inflammatory agents [6, 7]

Historically, marine-derived compounds have been utilized in traditional medicine for thousands of years. Early coastal civilizations used seaweeds, mollusks, corals, and fish oils for nutritional and medicinal purposes, including treatment of wounds and thyroid disorders. The first marine compound isolated for therapeutic use was alginate, discovered in 1881 from kelp, followed by major discoveries in the mid-20th century such as spongothymidine and spongouridine from marine sponges, which led to the development of the anticancer drug cytarabine and antiviral drug vidarabine [8]. Modern research continues to reveal novel marine metabolites with applications in treating cancer, infections, pain, and inflammatory diseases.

Among marine organisms, algae form one of the most vital groups due to their pharmaceutical and industrial importance. Marine algae are photosynthetic organisms rich in polysaccharides, vitamins, minerals, and antioxidants, contributing to their medicinal value [9]. Based on pigmentation and morphology, they are classified into three major groups: Rhodophyceae (red algae), containing phycoerythrin and phycocyanin pigments; Chlorophyceae (green algae), rich in chlorophyll a and b; and Phaeophyceae (brown algae), containing chlorophyll a, c, and fucoxanthin [10]. This classification highlights their biochemical diversity and the potential of each group in the pharmaceutical and nutraceutical industries.

Agar Profile
Agar is a polysaccharide obtained mainly from red algae (Rhodophyta), serving as a vital raw material in the pharmaceutical, food, and microbiological industries. The primary agar-producing genera are Gracilaria, Pterocladia, and Gelidium, each contributing uniquely to agar quality and yield.

Gracilaria [Fig:1]
Taxonomic Overview
- **Botanical Name:** Gracilaria spp.
- **Family:** Gracilariaceae
- **Order:** Gracilariales
- **Class:** Florideophyceae
- **Phylum:** Rhodophyta (Red algae)
- **Common Species:** G. edulis, G. corticata
- **Habitat:** Marine; intertidal and subtidal zones on rocks, sand, and mudflats.
- **Regions:** India, Indonesia, China, Philippines, Vietnam.

1. Pharmaceutical Uses
Agar extracted from Gracilaria is widely used in microbiological media as a solidifying agent and in the pharmaceutical industry for making capsules, emulsions, and sustained-release drug formulations. Its gel-forming ability also supports wound dressing and controlled drug delivery systems due to biocompatibility and non-toxicity.[11]

2. Pterocladia [Fig:2]
Taxonomic Overview
- Botanical Name: Pterocladia spp.
- **Family:** Gelidiaceae
- **Order:** Gelidiales
- **Class:** Florideophyceae

- **Phylum:** Rhodophyta
- **Common Species:** P. capillacea, P. lucida
- **Habitat:** Marine; rocky coastal areas in temperate waters.
- **Regions:** New Zealand, South Africa, Egypt, Mediterranean, and India.

Pharmaceutical Uses

Agar from Pterocladia is known for its high gel strength and purity, making it ideal for pharmaceutical applications such as ointment bases, suppositories, and culture media. Its refined agar is also used in dental impressions and tissue engineering materials.[12]

3. Gelidium [Fig:3]

Taxonomic Overview

- **Botanical Name:** Gelidium spp.
- **Family:** Gelidiaceae
- **Order:** Gelidiales
- **Class:** Florideophyceae
- **Phylum:** Rhodophyta
- **Common Species:** G. amansii, G. corneum
- **Habitat:** Marine; rocky intertidal and subtidal zones.
- **Regions:** Japan, Spain, Korea, Portugal, Chile.

Pharmaceutical Uses

Agar from Gelidium yields superior quality with excellent clarity and gel strength. It is used in pharmaceutical suspensions, capsules, and gel formulations. In biotechnology, Gelidium-derived agar is a preferred medium for bacterial and tissue culture due to its purity and consistency.[13]

Fig:1 Gracilariaceae

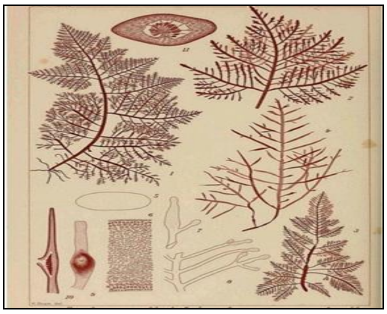

Fig:2 Pterocladiaceae

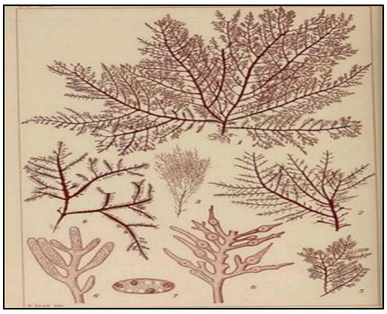

Fig:3 Gelidiaceae

Significance and Overview of Agar-Agar

Agar-agar is a polysaccharide-based hydrocolloid obtained from the cell walls of red algae (Rhodophyta), primarily from species such as Gracilaria, Gelidium, and Pterocladia. It is well known for its remarkable gelling and stabilizing properties, making it indispensable in food technology, pharmaceuticals, biotechnology, and microbiology. Agar consists of two main components agarose (responsible for gelling) and agaropectin (providing flexibility and viscosity). Its ability to form stable gels at low concentrations and remain solid over a wide temperature range has made it one of the most versatile seaweed-derived products worldwide.

Applications

1. Food Industry

Nearly 90% of the agar produced globally is utilized in food processing. It serves as a vegan gelatin substitute, thickener, stabilizer, and gelling agent in desserts, jellies, yogurts, and confectionery products. Agar improves the texture of baked goods and dairy products and is also used in soups and sauces. Edible films incorporating agar are now being explored for eco-friendly food packaging and preservation applications.[14]

2. Photographic and Industrial Uses

In photographic silkscreen printing, agar acts as a non-toxic base for emulsifying agents and printing pastes, ensuring excellent readability and adaptability. It also functions as a binder in light-sensitive emulsions such as cyanotypes and alternative photographic processes, contributing to long-lasting, high-quality prints.

3. Nanotechnology Applications

Agar has gained significance in nanotechnology for the preparation of composite films and biodegradable packaging materials. Melanin nanoparticle–agar composites show strong antioxidant and UV-blocking properties, making them suitable for biomedical and food packaging applications.

4. Pharmaceutical and Biomedical Applications

Pharmaceutically, agar is used as a gelation and thickening agent in capsules, emulsions, and topical preparations. Agar-based hydrogels and nanocomposites are being developed for
drug delivery, wound dressing, and cancer therapy. Its biocompatibility, stability, and non-toxic nature make it suitable for use in controlled release systems and biomedical implants.

5. Biotechnological and Microbiological Uses

Agar is an essential solidifying agent in microbial culture media (e.g., nutrient agar) and plant tissue culture. It supports cell growth, DNA/RNA blotting, and screening of recombinant colonies. Its stability at incubation temperatures makes it ideal for laboratory use, replacing gelatin in microbial studies. [14, 15]

Overview and Properties of Agar

Agar was first discovered in Japan during the 17th century and derived its name from the Malay word agar-agar, meaning “jelly.” Historically, it was used in Asian cuisines and later adopted in microbiology by Robert Koch in the 1880s as a culture medium due to its excellent thermal and physical properties.

Chemically, agar is composed of agarose (about 70%) and agaropectin (about 30%). It exhibits hysteresis—a property where it solidifies at 32–42°C (gel point) and melts at around 85°C (melting point). This allows agar to remain stable in gel form at body temperature, making it ideal for laboratory and pharmaceutical uses

Agar is derived mainly from red algae species such as Gelidium amansii, Pterocladia capillacea, and Gracilaria edulis. These algae, known as agarophytes, thrive in marine environments of Japan, India, China, and Southeast Asia. The global agar industry has since expanded, with large-scale production in Japan, China, and Indone. [16, 17].

Agar-agar is a natural, renewable marine biopolymer of immense scientific and industrial significance. Its diverse applications—from food to medicine and nanotechnology—underscore its value as a multifunctional material contributing to sustainable innovation and human welfare.

Industrial Production of Food Grade Agar-Agar

Agar-agar is a natural gelatinous substance obtained mainly from red algae such as Gelidium and Gracilaria. It serves as a vital gelling, thickening, and stabilizing agent in the food industry. The industrial production of food-grade agar-agar involves several key steps to ensure high-quality yield suitable for commercial use.

1. Plant Collection

The process begins with the identification and collection of suitable red algae species by experts. Ethnobotanical knowledge and marine field surveys help select species with optimal agar content and gelling properties. The harvested seaweeds are cleaned and sun-dried before further processing.[18]

2. Extraction

Agar extraction is the most critical phase of production. Seaweeds are boiled in water with mild acids or under pressure to release agar from the cell walls. Traditional extraction involves heating at temperatures above 100°C, while the pressure extraction method uses 1–2 kg/cm² pressure for 2–4 hours, reducing time and improving yield.

The alkali treatment (using NaOH or $CaCl_2$ at 85–90°C) is essential for Gracilaria species to improve gel strength by converting sulfated galactose into 3,6-anhydrogalactose. Other modern methods include polyphosphate extraction, freezing–thawing, and syneresis, which help refine agar quality and remove impurities

3. Photobleaching and Filtration

The photobleaching process is an eco-friendly step that enhances the gel's clarity and color by breaking down pigments under UV light. Hot-sol filtration ensures removal of insoluble residues. Automated filter presses are used in modern factories to maintain purity and hygiene.

4. Gel Dehydration and Drying

The agar gel obtained after filtration is dehydrated by freezing, pressing, or drying. Traditional "bar-style" and "stringy" agar are sun-dried or freeze-dried to retain strength and texture. Mechanical freezing methods are now used to produce high-quality dry agar flakes.

5. Isolation, Purification, and Quality Control

After extraction, the crude agar is purified through filtration and washing to remove salts and organic matter. Fractionation and chromatography methods ensure chemical purity. Each batch undergoes quality tests for gel strength, pH, and moisture content before packaging.[18]

Industrial agar production combines traditional techniques with modern technology to ensure consistency, safety, and superior gel performance, meeting international standards such as ISO 9000 for food-grade applications.

Industrial Visit to a Food Grade Agar-Agar Small Production Unit

An educational industrial visit was conducted to Shree Agar Agar Industry, located near Keeladi, Madurai, Tamil Nadu, to observe the production process of food-grade agar-agar on a small industrial scale. The visit provided practical exposure to the various stages of agar production from seaweed collection to packaging and offered insight into sustainable seaweed utilization and processing technologies used in Tamil Nadu's coastal belt.

Collection of Seaweeds

Seaweed collection forms the foundation of agar production. Both men and women of the Gulf of Mannar region actively participate in harvesting, which serves as a major source of livelihood. Seaweeds, primarily Gelidium and Gracilaria species, are collected during low tide or via small boats from shallow coastal waters (2–3 meters deep). Collectors wade into knee-deep waters, hand-picking the seaweeds and storing them in gunny bags (8–10 kg capacity) tied around their waist.[19]

In India, three cultivation techniques are predominantly **practiced:** raft culture, monoline culture, and tube-net culture. These methods enhance seaweed yield while maintaining ecological balance and quality.[20]

Preprocessing and Washing

The harvested seaweeds are washed thoroughly to remove sand, shells, salts, and debris. Gelidium species undergo simple washing, while Gracilaria requires alkali treatment to improve gel strength. The treatment involves heating the seaweed in 2–5% sodium hydroxide at 85–90°C for one hour, followed by neutralization with water or dilute acid. This chemical modification converts L-galactose sulfate into 3,6-anhydrogalactose, enhancing the gelling quality of agar.

Boiling and Filtration: [Fig:4]

Agar extraction is typically performed using hot-water or pressure methods.Gelidium is extracted under pressure at 105–110°C for 2–4 hours, producing higher yields.Gracilaria is boiled at 95–100°C for 2–4 hours.

The extract is filtered through coarse cloth or filter presses while kept hot to prevent premature gelation. Filtration removes solid residues and clarifies the extract.[21]

Cooling, Cutting, and Freezing: [Fig:5]

The filtered solution is poured into cooling trays or tanks, where it solidifies into a gel. The gel is cut into strips or blocks and pressed to remove excess water. The gel, containing about 1% agar, is then subjected to the freeze-thaw process, the most efficient dehydration method. Slow freezing forms large ice crystals that rupture the gel matrix, allowing water and impurities to drain off upon thawing. This increases agar concentration to 10–12%. The gel may also be pressed hydraulically to remove residual moisture.[22]

Bleaching and Drying
Bleaching enhances agar's whiteness and transparency. The filtered agar solution is treated with hydrogen peroxide (H_2O_2) or sodium hypochlorite (NaOCl) as bleaching agentis performed by either of the following methods:
Sun drying – Agar strips or flakes are laid on clean bamboo mats under sunlight for several days. It is cost-effective and eco-friendly, though dependent on weather conditions.
Hot air drying – Performed in ovens at 40–70°C, offering hygienic, faster, and uniform drying suited for commercial-scale production, though at higher energy cost.

Packaging and Product Forms: [Fig:7]
The dried agar is ground into flakes or fine powder, graded based on gel strength, clarity, and moisture content, and packed in moisture-proof containers or cartons for distribution. [23]. Two main forms are marketed:

1. **Agar Powder:** Produced industrially and used extensively in food, pharmaceutical, and microbiological applications.

2. **Agar Strips:** (Natural Agar) [Fig:6] – Made traditionally from Gelidium species through acidified boiling, followed by extrusion into spaghetti-like strands. These are freeze-thawed, sun-dried, and bleached naturally, maintaining their traditional appeal. The strips are bundled and sold for culinary use across Asia, requiring soaking before use to aid dissolution in boiling water.

Fig:4 Boiling

Fig:5 Cutter

Fig:6 Agar strips

Fig:7 Packaging of agar strips

Significance of the Visit
The industrial visit provided hands-on understanding of traditional and modern agar production techniques, small-scale industry operations, and quality enhancement through alkali treatment, filtration, and drying methods. The process demonstrated how local marine resources are sustainably converted into high-value industrial products through eco-friendly technology. Moreover, it highlighted the socio-economic importance of seaweed farming in Tamil Nadu's coastal regions and its growing contribution to the Indian marine bioproduct sector.

Acknowledgement
We express our deep sense of gratitude to Professor and faculty members of Department of Pharmacognosy, College of Pharmacy, Madurai Medical College for providing the guidance to carry out the studies.

Conclusion
The exploration of agar-agar production in the coastal belt of Tamil Nadu, particularly in the regions of Ramanathapuram, Madurai, and the Gulf of Mannar, demonstrates the immense potential of India's marine resources for sustainable economic and industrial growth. Derived from red algae such as Gracilaria, Pterocladia, and Gelidium, agar-agar serves as one of the most valuable marines bioproducts with diverse applications across the food, pharmaceutical, cosmetic, and biotechnological industries.
The study and industrial visit revealed that small-scale agar-agar industries effectively blend traditional extraction methods with modern processing techniques—including alkali treatment, filtration, photobleaching, and freeze-drying—to produce high-quality, food-grade agar. These locally operated units not only ensure resource utilization but also play a vital role in value addition and rural

employment generation. The active participation of coastal communities, particularly women, in seaweed collection and primary processing highlights the socio-economic significance of this industry in coastal livelihoods.

From a scientific and industrial standpoint, the development of agar-based biopolymers, nanocomposites, hydrogels, and culture media showcases the growing importance of marine biotechnology in advancing sustainable innovation. The classification and study of marine algae emphasize their biochemical diversity and the potential for discovering new bioactive compounds with medicinal and industrial relevance.

Looking forward, the future of agar-agar production appears highly promising. With increasing global demand for natural, biodegradable, and health-safe materials, there is great potential to expand small-scale and medium enterprises through government schemes, coastal aquaculture initiatives, and entrepreneurship programs. Financial assistance, technical training, and research collaborations can further enhance production efficiency and product quality.

In conclusion, agar-agar stands as a symbol of sustainable marine resource utilization, bridging traditional knowledge with scientific innovation. Its continued development not only supports environmental conservation and economic empowerment but also positions India as a potential leader in marine-based industries, contributing to both blue economy growth and rural development.

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