2. Seaweeds used as a source of agar

2.1 GENERA AND SPECIES USED

Most agar is extracted from species of *Gelidium* (Figure 1) and *Gracilaria* (Figure 2). Closely related to *Gelidium* are species of *Pterocladia*, and small quantities of these are collected, mainly in the Azores (Portugal) and New Zealand. *Gelidiella* acerosa is the main source of agar in India. *Ahnfeltia* species have been used in both Russia and Japan, one source being the island of Sakhalin (Russia).

2.2 NATURAL HABITATS

First, a discussion is necessary of the terms used to describe where seaweeds grow. The vertical dimension of the shore is divided into zones. Common terms used to describe these are the intertidal zone and the subtidal zone. People are familiar with tides and readily understand these terms. The intertidal zone is the part of the shore that lies between the high and low tide levels, the subtidal zone is everything below the low tide level. Sometimes

FIGURE 1
***Gelidium*, rehydrated from dried material purchased by an agar producer.**
The coin diameter is 20 mm.

FIGURE 2
***Gracilaria*, rehydrated from dried material purchased by an agar producer.**
The coin diameter is 20 mm.

the intertidal zone is called the littoral zone. However, it has been found that, from a biologist's point of view, it is better to use terms that define the zones by what usually grows in them. So a line is drawn, and above this line is a zone where organisms receive irregular wetting and this is called the eulittoral zone. Below this line, organisms are immersed in water except on rare occasions (e.g. extremely low tides); this is called the sublittoral zone. These zones do not necessarily depend on tide levels; the upper limit of the eulittoral zone is set by the upper limit of barnacles, where they occur, and the lower limit is the highest point where the large brown algae can be found growing. Above the edge of the eulittoral zone, beyond the barnacles, is a zone that is only reached by spray water and this is called the littoral fringe.

Gelidium grows best where there is rapid water movement, which is in the eulittoral and sublittoral zones. Depending on the species, it can be found in water from 2 to 20 m in depth. *Gelidium* prefers rocky areas with steep slopes, and is rarely found on muddy or sandy bottoms (compare *Gracilaria* below). It prefers partial shade and may be bleached by full intensity light in tropical latitudes. It usually grows best at 15–20°C, but can tolerate higher temperatures. It can survive in low nutrient conditions and some species adapt to low or high salinity.

For further detail see Santelices (1991).

Large beds of *Gracilaria* usually grow in the eulittoral zone, or just below it in the beginning of the sublittoral, on sandy or muddy sediments that are protected from waves. Sometimes it can be found free-floating in tidal lakes of salt or brackish water. It can adapt to large variations in growing conditions, such as freshwater dilution, increase in fertilizer concentration from runoff, and raised temperatures. Seawater temperatures of 20°C or higher are needed for at least three months of the year. It grows in a wide range of latitudes. It can survive being covered in sediment – growing again when water motion uncovers it.

2.3 SOURCES OF AGAROPHYTES

The harvests of *Gelidium* are spread over a wide geographical area. Large quantities are harvested on the north coast of Spain, the middle to southern end of the coast of Portugal, and the west coast of Morocco. Smaller amounts are found on the Bay of Biscay coast in the southwest of France. Prior to the Second World War, the *Gelidium* of Japan was the main source of the world's agar, but industrialization has led to depletion of the natural stocks, and today Japan harvests similar quantities to countries like Spain and Morocco. The Republic of Korea harvests commercial quantities for its local industry, in an area around the southern port of Pusan. In Mexico, *Gelidium* is harvested on the Pacific coast of Baja California. Warm-water species are collected from natural beds on the south coast of Java, Sumatra and many of the islands of Indonesia that lie between Java and Timor. Less significant contributors to the total harvest of *Gelidium* are Chile, China, France and South Africa.

For further details see McHugh (1991), and for an update on individual countries see Critchley and Ohno (1998).

Gracilaria is also distributed widely, with some species adapted to tropical countries like Indonesia, others to colder waters such as southern Chile and the Atlantic coast of Canada. Chileans pioneered the commercial cultivation of *Gracilaria*, using *Gracilaria chilensis*, native to its southern coast and containing a high quality agar. There are also large beds of wild Gracilaria in Chile, and it was the fear of depletion of these beds by overharvesting that led to the development of cultivation. Wild *Gracilaria* is also harvested in Argentina and Brazil, although the quantity is decreasing in Brazil because the quality does not compare well with the Chilean product.

China produces significant quantities of *Gracilaria*, mainly in the southern provinces of Guangxi and Hainan, where it is cultivated in ponds and estuaries; it is also cultivated in Taiwan Province of China. In Indonesia, wild seaweed is collected and some is cultivated

in ponds. A more concerted effort appears to have been made in Viet Nam in recent years, with a variety of species being grown in lagoons and ponds in both the north and south. Beach-wash *Gracilaria* has been collected near Luderitz (Namibia) for a number of years, and, more recently, successful cultivation has been achieved in Luderitz Bay. Since the Second World War, wild seaweed has been collected from Saldanha Bay on the west coast of South Africa, but the yearly harvest has shown wide fluctuations. In southern Thailand, a source of income for women is the collection of free floating *Gracilaria* from tidal lakes and lagoons (Figure 3).

2.4 HARVESTING METHODS FOR WILD AGAROPHYTES

For *Gelidium*, the harvesting methods used in Spain and Portugal are typical of the industry. A high percentage of the harvest comes from the gathering of storm-cast seaweed. This is often done by two people dragging a net to capture the seaweed; for cast material that has settled to the bottom in shallow bays, boats may be used to drag the nets. Sometimes significant quantities of cast seaweed collect in depressions in the sea floor and this is collected using a suction tube, put in place by a diver, to draw the material up and into a boat.

The harvesting of material that is still attached to the rock is often done by divers, who pluck off the seaweed and stow it in net bags or baskets, which are hauled into the service boat when full. However, plucking can lead to complete removal of the plant, and then regeneration of the beds is slower. The seaweed is held onto the rock by a holdfast, a structure that often consists of many finger-like pieces that are called rhizoids. It is important for some rhizoids to be left on the rock so the *Gelidium* can regrow. Machines, held by divers, for cutting or mowing the seaweed bed have been devised, usually with an attachment that sucks the cut weed up and into a boat. While the machines are expensive, they have the advantage of not damaging the holdfast and rhizoids, allowing faster recovery of the beds, which also show an increased mass of seaweed when they regrow. In several countries, such as Chile and Indonesia, most of the harvest is from attached weed that is picked by hand either at low tide or by snorkelling in shallow waters.

For *Gracilaria* that is growing on the bottom, as the plant enlarges it provides more resistance to water movement and may eventually break off, leaving some of the plant in the sediment or sand to grow again. The broken pieces drift and may be collected by nets or are picked up after they wash onto the shore. Raking the beds from a boat is also practised, but care is needed or the sea bottom may be damaged, leaving little residual plant to grow again. A harvesting strategy is needed to preserve *Gracilaria* beds, and this should take into consideration the

FIGURE 3
Negotiating a price for dried *Gracilaria*. Women derive an income from *Gracilaria* collection in southern Thailand.

best time or season to harvest, the harvesting frequency, the method used (such as dragging or plucking), the harvesting tools and the need to leave some material unharvested so that regrowth can occur. The farmgate price (price paid to the collectors) of *Gracilaria* varies with demand and collectors usually respond with heightened activity and a tendency to overharvest when the price is high, so there is a need to have an enforceable harvesting policy to preserve the natural beds. In Argentina, *Gracilaria* is gathered from large quantities brought ashore by storms; it is not harvested from attached material.

2.5 CULTIVATION OF AGAROPHYTES

Gelidium species are small, slow growing plants, and while cultivation in ponds and tanks is possible, to date it has not been economically viable. The only exception appears to be in the case of a Canadian company based near Vancouver, Marine Bioproducts International Corp. It claims to be growing a consistent, high quality *Gelidium* from which it produces speciality high grade agar and agarose products that presumably can be sold at a premium price to offset the costs of cultivation (details at www.marbio.com).

Gracilaria cultivation is widespread, and several methods are used. It can be grown vegetatively (i) in open waters on the bottom of bays, estuaries or reef flats; (ii) on lines, ropes or nets; (iii) in ponds; or (iv) in tanks. It has also been grown from spores, involving an alternation of generations and the need for nursery tanks to allow the germlings to grow before planting them out into the sea. The first three methods, (i) to (iii), are the most widely used ones.

Where the open-water bottom is a soft sediment, such as an intertidal mudflat or an estuary outlet, pieces of seaweed are forced into the sediment using a "y"-shaped fork planting tool, either by a diver or from a boat using a long wooden handle with the fork on the end. The buried portion of the plant grows laterally, anchoring the plant, and it also produces vertical shoots that develop into mature plants. When the bottom is sandy, forked pieces loosen before they can become established by growing new lateral shoots, so to overcome this a different method is used. Tubular plastic bags, about 1 m long by 30–40 cm diameter, are filled with sand, and pieces of seaweed are wound around the tube or fixed to it with an elastic band. The tubes are then placed on the sea bottom and the plant is held in place as it forms new horizontal shoots. Eventually the plastic bag disintegrates, but by then the plant is firmly attached to the bottom. However, the accumulation of large quantities of disintegrated plastic tubes, washed up on nearby shores, can be a problem. Other methods have included fixing pieces of seaweed to rocks using rubber bands or nylon mesh to hold it in place on the rock, and then placing the rocks on the sea bottom.

For further detail, Buschmann, Westermeier and Retamales (1995) give a summary of experiences with sea-bottom farming in Chile; see also the more general references at the end of this section.

Line or rope farming was pioneered in China in the 1950s for the cultivation of brown seaweeds, and the method has been adapted to several other genera, including *Gracilaria*. Pieces of *Gracilaria* are fixed to a rope or monofilament line such as nylon. The rope needs to be stable when exposed to sunlight and salt water for long periods; polypropylene rope is often used. The seaweed can be attached by untwisting the rope to open the lay, inserting the plant and then allowing the rope to twist back to its natural position. Or the plant may be tied to a monofilament line, or a rope, with another piece of "string" – often a plastic raffia is used. The line is then stretched in the water between two stakes driven into the bottom. Success depends on the selection of farm site (suitable water flow, nutrient availability and water temperature) and positioning of the line in relation to water depth and light intensity. These are general guidelines, and adjustments must be made for each site. Nets can be used in place of ropes, but people generally find ropes are more convenient. Sometimes the ropes or nets are fixed to frames made from bamboo, giving a raft type structure (see Figure 42) that is anchored to the sea bottom and held at a fixed depth with floats.

Pond cultivation of *Gracilaria* is less labour intensive than rope farming (no need to fix many pieces to a rope or net) and has been quite successful, originally in China in Guandong, Hainan and Taiwan Province of China, now also in Indonesia, Viet Nam and in experimental trials in Malaysia. One disadvantage of *Gracilaria* from ponds is that the agar extracted from it is often of low gel strength and so only attracts the lower price of a food grade agar. Ponds are usually no larger than a hectare, preferably 0.5–1.0 ha. Pieces of fresh seaweed, either gathered from natural beds or nearby ponds, are broadcast evenly over the pond surface and allowed to sink to the bottom. Because the *Gracilaria* is not fixed in any way, any wind motion of the water will drive the plants to one side of the pond. This even occurs in small ponds, so an area that is not exposed to strong winds is preferable. Ponds need access to both salt and freshwater so that the salinity can be adjusted and so that the water can be changed every 2–3 days. Water change is usually made using tidal flows, with gates to control the water flow in and out.

Frequently, old shrimp or fish ponds are used (Figure 4). The pH of the pond water is important, and newly constructed ponds are often too acidic and must be left to rest until the pH is just slightly alkaline (pH 8). Pond depths are usually 60–70 cm, but the water level may be varied according to the air temperature. The preferred water temperature is 15–30°C so, for example, in the summer of Taiwan Province of China, if the air temperature rises above 30°C, the water depth is increased to 50–60 cm to protect the seaweed from hot surface temperatures. In the colder winter months, the water level may be reduced to 20–30 cm to allow warm water to reach the bottom.

Harvesting is possible every 35–45 days depending on the seasonal growth rate. About half the seaweed is harvested, usually by people wading through the pond, scooping it off the bottom into nets and placing it on a wooden raft or floating basket (Figure 5). The plants remaining form seed material for the next crop, and are broken into smaller pieces and broadcast over the pond. The harvested material is often laid around the banks of the pond to dry in the sun for 2–3 days (Figure 4), although a cleaner product is obtained by drying away from the ground (Figure 6).

An epiphyte is a plant that grows on another plant but is not parasitic on it. Epiphytes can be a problem in all seaweed cultivation since they contaminate the crop unless they are removed. In the pond cultivation of *Gracilaria*, epiphytes can be a particular problem because the growing seaweed is not readily accessible to the farmer, as it lies on the bottom of the pond. Contrast this with cultivation on lines, where the farmer can periodically move along the lines and physically remove epiphytes at an early stage of contamination. Sometimes *Gracilaria* is grown in ponds with other marine species, such as tilapia or milkfish, that will control the epiphytes by grazing on them. This and other types of polyculture are discussed in more detail in a later section (Section 9.6).

FIGURE 4
Pond used for *Gracilaria* cultivation, Sulawesi, Indonesia.

FIGURE 5
Harvesting *Gracilaria* from pond cultivation, Sulawesi, Indonesia

FIGURE 6
Drying *Gracilaria*, off the ground, Pattani, southern Thailand.

For further detail on epiphytism, see a review of epiphytism and its control in *Gracilaria* farming in Fletcher (1995).

Tank cultivation of *Gracilaria* has been studied by several groups. Because other methods of cultivation are relatively labour intensive, in developed countries it was thought that tank cultivation of unattached plants might be the answer to their high labour costs. However, it has not been adopted on a commercial scale because of the costs involved. The method is very energy intensive because of the need for aeration and large amounts of flowing seawater. Nutrients must also be added, and sometimes the temperature needs to be controlled, particularly in hot climates. Commercial scale production also brings a requirement for large areas of coastal land, and this can be very expensive in developed countries.

For further details

The cultivation of *Gracilaria* has been the subject of some very good reviews that give details of the processes involved and useful explanatory diagrams. See Ohno and Critchley (1993), Santelices and Doty (1989), Oliveira, Alveal and Anderson (2000), and Buschmann et al. (2001).

In addition, the June 1995 issue of the Journal of Applied Phycology is devoted to 10 papers given at a workshop on *Gracilaria* and its cultivation; each of the following papers is useful for the particular topic, which can be found in its title (see list of References): Buschmann, Westermeier and Retamales (1995); Dawes (1995); Friedlander and Levy (1995); and Fletcher (1995).

2.6 QUANTITIES HARVESTED

For *Gracilaria*, Chile is the largest supplier, although the harvest of wild seaweed has fluctuated over the last 5 years, from 121 000 wet tonnes in 1996 down to 73 000 tonnes in 1998, and back up to 137 000 wet tonnes in 2000. Cultivation has yielded about 33 000 wet tonnes for the last two years for which figures are available (1999 and 2000). China, Indonesia, Namibia and Viet Nam all supply between 12 000 and 18 000 wet tonnes each, in most cases from a mixture of wild and cultivated material. In Argentina, between 1985 and 1995, the harvest of dried *Gracilaria* varied from 1 700 to 3 100 tonnes. In India, harvests of wild *Gracilaria* and *Gelidiella* on the Tamil Nadu coast have varied between 750 and 1 300 dry tonnes from 1996 to 1999.

For *Gelidium*, the main suppliers in Europe are Spain and Portugal; in Africa, it is mainly from Morocco, with some from Namibia and South Africa. The principal contributors from Asia-Pacific are Japan, the Republic of Korea and Indonesia, while from the Americas it is Mexico.

Quantities harvested from the principal source areas are shown in Table 1.

TABLE 1
Agarophyte resources harvested in 2001 (tonnes dry weight)

Gracilaria	
Europe	200
Africa	300
Americas	25 000
Asia-Pacific	11 500
Subtotal	37 000
Gelidium	
Europe	6 600
Africa	7 200
Americas	500
Asia-Pacific	4 300
Subtotal	18 600
Pterocladia	
Europe	50
Total	55 650

Source: H. Porse, CP Kelco ApS, 2002, *pers. comm.*

2.7 MARKETS

Gelidium is sold to agar producers. In Japan, Mexico, Morocco, Portugal and Spain, the harvests are sold to local agar companies. *Gelidium* is such an excellent source of high quality agar that there is always a strong demand from any agar producer in the country of origin. However, price is always a determining factor and, for example, Spain has imported *Gelidium* from South Africa and Chile when the local price was too high. Indonesian *Gelidium* is used by local agar producers and some is also exported, mainly to Japan. Chile and South Africa both sell *Gelidium* to the producers in Europe and Japan; according to official statistics, *Gelidium* is not extracted in Chile and there are no agar producers in South Africa.

Chile has six exporters of *Gelidium*, listed by ProChile, but two of these dominate the trade: Industria Pesquera Costa Azul S.A., Vina del Mar; and Midesa S.A.C., Santiago.

A South African exporter is Taurus Products (Pty) Ltd, Johannesburg.

The numbers and names of Indonesian exporters of *Gelidium* fluctuate and current information is best obtained from the Indonesian Seaweed Industry Association (APBIRI) (See Section 3.2).

Gracilaria is sold to agar producers and some is used as food. For food consumption, the seaweed is usually gathered and sold fresh, locally. It is most common in South-East Asian countries such as Indonesia, Malaysia, the Philippines and southern Thailand, mainly in coastal communities. It is also popular with most ethnic groups in Hawaii, and is sold fresh in Honolulu markets as limu manauea or limu ogo.

Agar producers usually buy dried *Gracilaria*, but some buyers, particularly from Japan, are now requiring alkali-treated, dried seaweed. Historically, Japan produced agar by extracting the seaweed, *Gelidium*, with hot water and then freezing the extract by placing it outside in the winter sub-zero temperatures. Consequently several agar producers are located in mountainous districts of Japan, where it is becoming increasingly difficult to dispose of waste waters. To obtain a good quality agar from *Gracilaria*, it is necessary to treat it with alkali before the hot water extraction (more details in Section 3), and it is the disposal of these alkaline waste waters that is posing environmental problems. Buying *Gracilaria* that has already been treated with alkali overcomes this problem for Japanese producers. However, it means that some exporters now have to set up alkali treatment facilities in their own countries. Japan imports *Gracilaria* mainly from Chile, Indonesia,

Namibia, the Philippines and South Africa. Other importers are Argentina, the Republic of Korea and Spain. Chile is the largest exporter of Gracilaria, but also uses appreciable quantities itself; in the case of Indonesia and Viet Nam, each uses about one-third of its production, exporting the remainder. Other exporters include Namibia and South Africa.

Chile lists 21 exporters of *Gracilaria*, the largest ones being Algas Vallenar S.A., Vallenar; Algas, Cultivos, Exportaciones – Acex S.A., Santiago; Alimentos Multiexport S.A., Santiago; and Midesa S.A.C., Santiago. For up-to-date information on Chilean exporters, consult the latest annual Export Directory, published by ProChile, Santiago.

A South African/Namibian exporter is Taurus Products (Pty) Ltd, Johannesburg.

The numbers and names of Indonesian exporters of *Gracilaria* fluctuates and current information is best obtained from the Indonesian Seaweed Industry Association (APBIRI) (See Section 3.2).

2.8 FUTURE PROSPECTS

Sales depend on the prosperity of the agar industry, and since it has a stable market with limited prospects of expansion, agarophytes in general are in a similar position. However, the market for *Gelidium* and *Pterocladia* will always be competitive because they provide the best quality agar and are only available from limited natural resources. Since the cultivation of *Gracilaria* has been so successful, this means that any expansion that does occur in the agar market can be readily serviced by growing more *Gracilaria*. At present the producers and collectors of *Gracilaria* are therefore likely to face a buyers market, bringing pressure to reduce prices.

3. Agar

3.1 AGAR PRODUCTION METHODS

3.1.1 Food grade agar

A short and simplified description of the extraction of agar from seaweeds is that the seaweed is washed to remove foreign matter and then heated with water for several hours. The agar dissolves in the water and the mixture is filtered to remove the residual seaweed. The hot filtrate is cooled and forms a gel (jelly) which contains about 1 percent agar. The gel is broken into pieces, and sometimes washed to remove soluble salts, and, if necessary, it can be treated with bleach to reduce the colour. Then the water is removed from the gel, either by a freeze-thaw process or by squeezing it out using pressure. After this treatment, the remaining water is removed by drying in a hot-air oven. The product is then milled to a suitable and uniform particle size.

However, for a better understanding of the process, some of the details and difficulties need to be described.

There are some differences in the treatment of the seaweed prior to extraction, depending on the genus used. *Gelidium* is simply washed to remove sand, salts, shells and other foreign matter and is then placed in tanks for extraction with hot water. *Gracilaria* is also washed, but it must be treated with alkali before extraction; this alkaline pre-treatment causes a chemical change in the agar from *Gracilaria*, resulting in an agar with an increased gel strength. Without this alkaline pre-treatment, most *Gracilaria* species yield an agar with a gel strength that is too low for commercial use. For the alkali treatment, the seaweed is heated in 2–5 percent sodium hydroxide at 85–90°C for 1 hour; the strength of the alkali varies with the species and is determined by testing on a small scale. After removal of the alkali, the seaweed is washed with water, and sometimes with very weak acid to neutralize any residual alkali.

For the hot-water extraction, *Gelidium* is more resistant and extraction under pressure (105–110°C for 2–4 hours) is faster and gives higher yields. *Gracilaria* is usually treated with water at 95–100°C for 2–4 hours. The remainder of the process is the same for both types of raw material. The hot extract is given a coarse filtration to remove the seaweed residue, filter aid is added and the extract is pumped through a filter press equipped with a fine filter cloth. The extract is thick and will gel if allowed to cool, so it must be kept hot during the filtration processes.

The filtrate is now cooled to form a gel, which is broken into pieces (Figures 7 and 8). This gel contains about 1 percent agar. The remaining 99 percent is water that may contain salts, colouring matter and soluble carbohydrates. The gel may be treated with bleach to reduce any colour, washed to remove the bleach, and allowed to soak in water so that most of the salts can be removed by osmosis. The wash waters are drained and the remainder of the process is concerned with the removal of the 99 percent water in the gel. Either of two methods can be used for this.

The original method of water removal is the freeze-thaw process. The gel is slowly frozen so that large ice crystals form. The structure of the gel is broken down by the freezing so that when the material is thawed most of the water drains away, leaving a concentrated gel that now contains about 10–12 percent agar (this means about 90 percent of the original water content has been removed, and with it went a high proportion of any salts, soluble carbohydrates and soluble proteins that may have been present in the gel). Sometimes this gel is placed between porous filter cloths and squeezed in a hydraulic press to remove more water. However, this is a slow process, and usually the thawed material is simply

FIGURE 7
Hot agar solution is fed, from the T-shaped PVC pipe, as a thin layer onto a stainless steel belt where it is cooled and forms a gel.

FIGURE 8
Pieces of gel breaking up as they fall off the end of the stainless steel cooling belt. A cutting device, consisting of a stainless steel screw and thin wire, is at the bottom of the ramp.

drained and placed in a hot-air dryer. After drying it is milled to the required particle size, usually about 80–100 mesh size. Because of the refrigeration costs, this freeze-thaw process is relatively expensive, compared to the alternative described next.

Sometimes the thawing is accelerated by washing the frozen blocks of gel with large quantities of water (Figure 9), but this adds to the already large water consumption of the process.

The alternative process relies on synaeresis. This is the term used to describe the separation of liquid from a gel. A common example is that of a partly used jar of jam or preserves that is left standing for several days: pools of liquid can often be seen at the surface. However, for the agar gel, pressure is used to force the separation of the liquid. The equipment used is based on the following. Two grooved metal plates are covered with porous cloth and the 1 percent agar gel is placed between the cloths, like a sandwich with metal plates on the outside, then the layers of cloth, with the gel in the middle. Pressure is applied to the metal plates and very slowly increased over about 24 hours, forcing liquid out of the gel, through the cloths, down the grooves of the metal plate and away to a drain. The piece of equipment contains about fifty of these sandwich-type units, all in a vertical plane, all being placed under pressure by one hydraulic ram (Figure 10). At the end of the time, the pressure is released, the metal plates are separated and the remaining gel, now containing about 20 percent agar, is peeled off the porous cloth (Figure 11). It is shredded and dried in a hot-air oven before being milled to the required particle size, usually about 80–100 mesh size. With no refrigeration required, the energy consumption is obviously much lower than

FIGURE 9
Thawing frozen slabs of agar by hosing with water.

FIGURE 10
Dewatering machine used to squeeze water from agar gel.

FIGURE 11
A sheet of agar gel after squeezing in the dewatering machine.

for the freeze-thaw method, and, since more water has been removed, less soluble matter remains, so the agar is more pure. Less energy is also needed in the drying process since less water is being removed. This process based on synaeresis has been widely adopted by large agar producers who can afford the higher capital costs for this equipment.

FIGURE 12
Agar blocks (left) and agar strips (right).

FIGURE 13
Flow chart for the production of agar (after Armisen and Galatas, 1987).

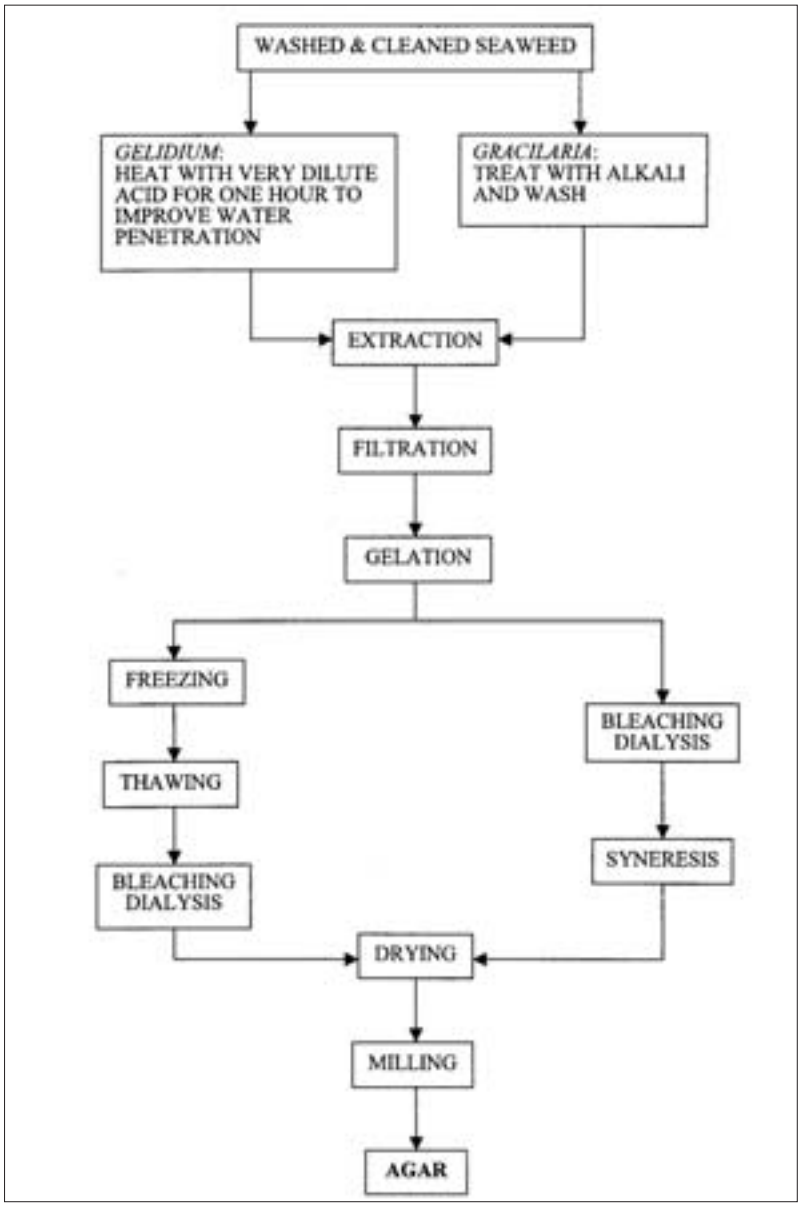

Figure 13 summarizes the production processes for agar.

A large and reliable freshwater supply is a requirement for an agar factory. Water consumption is high and the processing of *Gracilaria* requires more than for *Gelidium*. Higher water consumption also means larger quantities for waste disposal, so recycling of water is becoming more necessary, depending on the location of the factory.

For further details

Detailed information on the commercial extraction process is not easily available. There are several short publications on the results from laboratory-scale extractions, but commercial agar producers are generally secretive about the details of their processes. Armisen and Galatas (1987) is one of the few publications that gives some details, but there are still many gaps, particularly in the conditions of the alkali treatment and the subsequent hot water extraction; nevertheless, it is the best starting point. The original print version may not be readily available but it can be read and downloaded from the FAO Web site (see References 2 – Internet sources). A later book chapter by the same authors, Armisen and Galatas (2000) gives a useful comparison of the freeze-thaw and synaeresis methods for removing water from the agar gel. Nussinovitch (1997: 4–5) also has a few useful details about extraction.

3.1.2 Agar strips

Agar for use in food is sold in two forms: strip agar and agar powder. The powder is produced by the method previously described. Agar strip, sometimes called natural agar, is produced on a small scale in China, Japan and the Republic of Korea by the old, traditional method. *Gelidium* must be used; it was the only raw material used before the Second World War. It is boiled for several hours in water, acidified by the addition of either vinegar or dilute mineral acid. The hot extract is filtered through cotton cloth, then poured into wooden trays to cool and form a gel. The gel is extruded to produce spaghetti-type strips about 30 cm long. The strips are placed outside at night to freeze and allowed to thaw in the day, so water is released and runs off, leaving a more concentrated gel. This process can be repeated, or modern refrigeration can be substituted. The strips are dried in the sun, which also bleaches the strips. Strips are assembled into bundles and sold for domestic use (Figure 12). Prior soaking makes them easier to dissolve in boiling water.

3.1.3 Bacteriological agar

This can only be made from species of *Gelidium* because the resulting agar has a low gelling temperature (34–36°C) that allows the addition of other materials to the agar with a minimum risk of heat damage. *Gracilaria* and *Gelidiella* give agars that gel at 41°C or higher. "Bacto" agars must not contain anything that might inhibit the growth of bacteria, such as trace metals, soluble carbohydrates or proteins, nor should they contain any bacterial spores. They must not interact with any materials that must be added as nutrients for the bacteria under study. The gels must be strong and have good clarity. Manufacturers of bacteriological agar keep all processing details confidential. However, recently Kim et al. (2000) published details [in Korean] of a pilot-scale preparation that they claim gave a product that is superior to commercial bacteriological agar. Armisen and Galatas (1987) and Armisen (1997) discuss the necessary specifications for bacteriological agar.

3.1.4 Agarose

Agar can be divided into two principal components: agarose and agaropectin. Agarose is the gelling component; agaropectin has only a low gelling ability. There are several methods of producing agarose; many rely on removing the agaropectin from the agar. There are only a small number of processors who produce purified, high quality agarose for a small but growing market, mainly in biotechnology applications. These processors use good quality agar as their starting material rather than seaweed, and are often not in the seaweed processing business. Armisen and Galatas (1987) summarize the methods that have been used to isolate agarose from agar, and discuss the specifications expected for a high quality agarose.

3.2 AGAR PRODUCERS

A summary of the capacity of agar producers according to their broad geographical location is given in Table 2.

The principal agar producers are listed below.

TABLE 2
Agar processors. Capacity in tonnes (2001)

Europe	780	10 percent
Africa	1 050	14 percent
Americas	3 000	39 percent
Asia-Pacific	2 800	37 percent
Total	77 630	

Source: H. Porse, CP Kelco ApS, 2002, *pers. comm.*

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Website: www.hispanagar.net
This is the largest Spanish phycocolloid factory, which produces food and bacteriological grade agars, Purified Bacteriological Agars (for use with specially sensitive bacteria and in bacterial metabolism assays as well as in biochemistry). They also produce many different types of agarose for biochemistry and molecular biology, being the world's largest producer of agaroses.

Industrias Roko, S.A.
Rua os Regos 27
Oleiros,
La Coruña 15173
Tel: [INT+34] +981 631 159
Situated near Oviedo, it produces food grade agar and some types of bacteriological agar.

Algas de Asturias, S.A.
LG Bria - Posadas de Llanes
Llanes - Asturias
A smaller factory that produces food grade agar and some types of bacteriological agar.

Portugal

Iberagar S.A.
Estrada Nacional 10, Km. 18, Coina
Tel: [INT+35] +(121) 210 9252
Fax: [INT+35] + (121) 210 9255
Website: www.iberagar.com
Produces food and bacteriological grade agars.

Morocco

SETEXAM, S.A
Km 7 Route de Tanger,
B.P. 210
14000, Kenitra
Tel: [INT+212] + 7 378 496
Fax: [INT+212] + 7 378 448

Marokagar, S.A.
44 Rue Abou Baker Wahrani
B.P. 2121
Casablanca 05
Tel: [INT+212] + 2 623 611
Fax: [INT+212] + 2 614 895

Chile

Algas Marinas S.A. (Algamar)
Fidel Oteiza 1956 Piso 14
Providencia, Santiago
Tel: [INT+56] + (2) 205 5086
Fax: [INT+56] + (2) 205 5184

Prodoctora de Agar S.A. (Proagar S.A.)
Av. Vicente Perez Rosales 800
Llanquihue
Tel: [INT+56] + (65) 242 635
Fax: [INT+56] + (65) 243 312
In 2000, this Japanese controlled company claimed to be the world's second-largest agar producer, exporting about 450 tonne/year.

Agar del Pacifico S.A.
Av. Federico Schwager 1112 -
Parque Industriel Coronel
Coronel
Tel: (56-41) 75 1286
Fax: (56-41) 75 1143

Cobra Chile S.A.
Av. Andres Bello 1051 Of. 2501
Providencia, Santiago
Tel: [INT+56] + (2) 236 1582
Fax: [INT+56] + (2) 236 0276

Japan
Ina Food Industry Co., Ltd.
574 Tsurumakicho, Waseda
Shijuku
Tokyo 162
Tel: [INT+81] + (3) 3235 8861
Fax: [INT+81] + (3) 3235 8863

Matsuki Agar-Agar Industrial Co., Ltd
2638 Miyagawa
Chino City
Nagano-Pref
Tel: [INT+81] + (266) 724 121

The Republic of Korea
Myeong Shin Chemical Ind. Co., Ltd.
2191-3 Songbaek Sannae
Milyang, Kyeongnam
Tel: [INT+82] + (55) 352 0547
Fax: [INT+82] + (55) 352 0548
Website: www.miryangagaragar.com
(agar factory)

Myeong Shin Chemical Ind. Co., Ltd.
439-13, Soju-Ri, Ungsang-Up,
Yangsan-gun, Kyeong-Nam,
Tel: [INT+82] + (55) 389 1001
Fax: [INT+82] + (55) 389 0478
(Head Office and carrageenan factory)

Indonesia
P.T. Agarindo Bogatama
Jl. Gajah Mada No. 3
Komplex Duta Merlin Blok E No.34-35
Jakarta 10130

For further details about Indonesia and other Indonesian companies contact the Indonesian Seaweed Industry Association (APBIRI)
Asosiasi Pengusaha Budidaya dan Industri Rumput Laut Indonesia (APBIRI)
BPPT Lt. 13
Jl. MH Thamrin No. 8
Jakarta Pusat 10340
Tel: [INT+62] + 21 322430

Mexico
Agarmex S.A.
Ensenada

New Zealand
Coast Biologicals Ltd
Factory Road
Opotiki
Tel: [INT+64] + 7 315 7663
Fax: [INT+64] + 7 315 8002
Produces only bacteriological agar from Pterocladia.

France
SOBIGEL S. A.
Rue de L'industrie B.P. 304
64703 Hendaye
Tel: [INT+33] + (55) 9201844
Fax: [INT+33] + (55) 9202362
Owned by Hispanagar, S.A.

Argentina
Soriano S.A.
9 de Julio 745
9100 Trelew
PCIA Chubut

3.3 AGAR USES

The uses of agar centre around its ability to form gels, and the unique properties of these gels. Agar dissolves in boiling water and when cooled it forms a gel between 32° and 43°C, depending on the seaweed source of the agar. In contrast to gelatin gels, that melt around 37°C, agar gels do not melt until heated to 85°C or higher. In food applications, this means there is no requirement to keep them refrigerated in hot climates. At the same time, they have a mouth feel different from gelatin since they do not melt or dissolve in the mouth, as gelatin does. This large difference between the temperature at which a gel is formed and the temperature at which it melts is unusual, and unique to agar. Many of its applications take advantage of this difference.

For details on the chemistry of why and how agar forms gels see Nussinovitch (1997) or Armisen and Galatas (2000).

3.3.1 Food

About 90 percent of the agar produced is for food applications, the remaining 10 percent being for bacteriological and other biotechnology uses. Agar has been classified as GRAS (Generally Recognized As Safe) by the United States of America Food and Drug Administration, which has set maximum usage levels depending on the application. In the baked goods industry, the ability of agar gels to withstand high temperatures means agar can be used as a stabilizer and thickener in pie fillings, icings and meringues. Cakes, buns, etc., are often pre-packed in various kinds of modern wrapping materials and often stick to them, especially in hot weather; by reducing the quantity of water and adding some agar, a more stable, smoother, non-stick icing is obtained.

Some agars, especially those extracted from *Gracilaria chilensis*, can be used in confectionery with a very high sugar content, such as fruit candies. These agars are said to be "sugar reactive" because the sugar (sucrose) increases the strength of the gel. Because agar is tasteless, it does not interfere with the flavours of foodstuffs; this is in contrast to some of its competitive gums that require the addition of calcium or potassium salts to form gels. In Asian countries, it is a popular component of jellies; this has its origin in the early practice of boiling seaweed, straining it and adding flavours to the liquid before it cooled and formed a jelly. A popular Japanese sweet dish is *mitsumame*; this consists of cubes of agar gel containing fruit and added colours. It can be canned and sterilized without the cubes melting. Agar is also used in gelled meat and fish products, and is preferred to gelatin because of its higher melting temperature and gel strength.

In combination with other gums, agar has been used to stabilize sherbets and ices. It improves the texture of dairy products like cream cheese and yoghurt. It has been used to clarify wines, especially plum wine, which is difficult to clarify by traditional methods. Unlike starch, agar is not readily digested and so adds little calorific value to food. It is used in vegetarian foods such as meat substitutes.

3.3.2 Other uses

In the pharmaceutical industry agar has been used for many years as a smooth laxative.

In orchid nurseries, agar gels containing appropriate nutrients are used as the growth substrate to obtain clones or copies of particular plants. Meristems – the part of the plant with actively dividing cells, usually the stem tips – are grown in the gel until there has been sufficient root development and growth for them to be transplanted. An advantage of this system is that the plants can be cultured in a sterile environment.

3.3.3 Microbiological agar

Bacteriological agar is used in testing for the presence of bacteria. It is specially purified to ensure that it does not contain anything that might modify bacterial growth. It is therefore more expensive, frequently at least twice the price of food grade agar. A hot agar solution (1–1.5 percent) is prepared and as it cools, nutrients or other chemicals specific for the type of bacteria being tested are added. When the solution has cooled below its gel point, the sample suspected of containing bacteria is spread on the surface of the gel, which is then covered and stored at a temperature suitable for bacterial growth. The agar gel should be as clear as possible so that any bacterial growth can be easily seen.

For further details

Further information about the uses of agar can be found in Glicksman (1983) and Armisen and Galatas (1987, 2000). Armisen and Galatas (2000) also contains some interesting recipes for yokan (traditional Japanese), sweet potato dessert (traditional Argentinian) and sugar icings, all of which illustrate typical methods for using agar in foods. Armisen (1997) lists eleven important advantages enjoyed by agar in food applications. Armisen (1995) is a paper about the use and importance of *Gracilaria*, but it also has useful discussions about

natural and industrial agars, compares the characteristics of agars from *Gelidium* and from *Gracilaria*, and is useful background reading for those wishing to learn more about the agarophyte and agar industries.

3.4 MARKETS AND MARKETING OF AGAR

A summary of the agar markets is shown in Table 3. It does not include production from *Gelidiella acerosa* and *Gracilaria* species in India, where 800–1 300 dry tonnes of seaweed are used to produce 100–160 tonnes/year of agar.

All the companies previously listed as agar producers sell directly to agar users. However, there are other companies that buy from producers and re-sell the agar, either alone or in admixture with other hydrocolloids, to users. These companies specialize in supplying food ingredients, usually defined as food additives that improve the quality, texture, stability or presentation of a food product. Because they are more active in the carrageenan and alginate industries, further discussion about them can be found later, in the relevant sections.

TABLE 3
Agar markets (2001)

Markets by application

Application	tonnes	percent
Food	6 930	91
Bacteriological	700	9
Total	7 630	

Markets by grade and source

Grade / seaweed	tonnes	percent
Powder / ***Gracilaria***	4 100	54
Powder / ***Gelidium***	2 305	30
Square / ***Gracilaria***	250	3
Strips / ***Gracilaria***	275	4
Bacto / ***Gelidium***	700	9
Total	7 630	

NOTE: The total market has a value of about US$ 137 million.
Source: H. Porse, CP Kelco ApS, 2002, *pers. comm*.

Some future prospects for the red seaweed industry and its hydrocolloid products are considered by Kapraun (1999).

3.5 FUTURE PROSPECTS

The market for food grade agar is stable and not likely to expand very much in the near future, unless new uses are developed, and this does not seem likely at present. During the last 30–40 years agar has gradually been replaced in some of its traditional uses by other hydrocolloids that either gave a better result in particular applications or are cheaper. Uses now are restricted to those that depend on the unique gelling properties of agar. There are many producers, some endeavouring to capture market share with low price or low quality material, so it is becoming a very tight market. The bacteriological agar market is also stable, but present prospects are that it is unlikely to show much expansion in the next five years. The market for agarose will expand during the next five years as its uses in biotechnology increase and probably diversify as new techniques are developed. However, it is a specialized and relatively small market; users often purchase in lots of 100 g, with a total worldwide consumption of about 50 tonne/year.