6. Seaweeds used as a source of carrageenan

6.1 GENERA AND SPECIES USED

Most carrageenan is extracted from *Kappaphycus alvarezii* and *Eucheuma denticulatum*. The original source of carrageenan was *Chondrus crispus*, and this is still used to a limited extent. *Betaphycus gelatinum* is used for a particular type of carrageenan. Some South American species that have previously been used to a limited extent are now gaining favour with carrageenan producers as they look for more diversification in the species available to them and the types of carrageenan that can be extracted. *Gigartina skottsbergii*, *Sarcothalia crispata* and *Mazzaella laminaroides* are currently the most valuable species, all collected from natural resources in Chile. Small quantities of *Gigartina canaliculata* are harvested in Mexico. *Hypnea musciformis* has been used in Brazil.

Over the last few years most of these seaweeds have been reclassified by marine biologists as they gain more knowledge of their structure. If readers are to go beyond this publication for further information, they need to be familiar with the both the old and new names, as listed below.

- *Betaphycus gelatinum* was *Eucheuma gelatinae*.
- *Chondrus crispus* remains unchanged, and is commonly known as "Irish Moss."
- *Eucheuma cottonii* is now *Kappaphycus alvarezii*, and commercially was and is called "cottonii".
- *Eucheuma denticulatum* was *Eucheuma spinosum* and commercially was and is called "spinosum".
- *Eucheuma gelatinae* is now *Betaphycus gelatinum*.
- *Eucheuma spinosum* is now *Eucheuma denticulatum* and commercially was and is called "spinosum".
- *Gigartina canaliculata* remains unchanged.
- *Gigartina skottsbergii* remains unchanged.
- *Gigartina stellata*, mentioned in earlier articles but now not so important, is now *Mastocarpus stellatus*.
- *Hypnea musciformis* remains unchanged.
- *Iridaea ciliata* is now *Sarcothalia crispata*.
- *Iridaea laminaroides* is now *Mazzaella laminaroides.*
- *Kappaphycus alvarezii* was *Eucheuma cottonii* and commercially was and is called "cottonii".
- *Mazzaella laminaroides* was *Iridaea laminaroides*.
- *Mastocarpus stellatus* was *Gigartina stellata*, mentioned in earlier articles but now not so important.
- *Sarcothalia crispata* was *Iridaea ciliata*.

6.2 NATURAL HABITATS

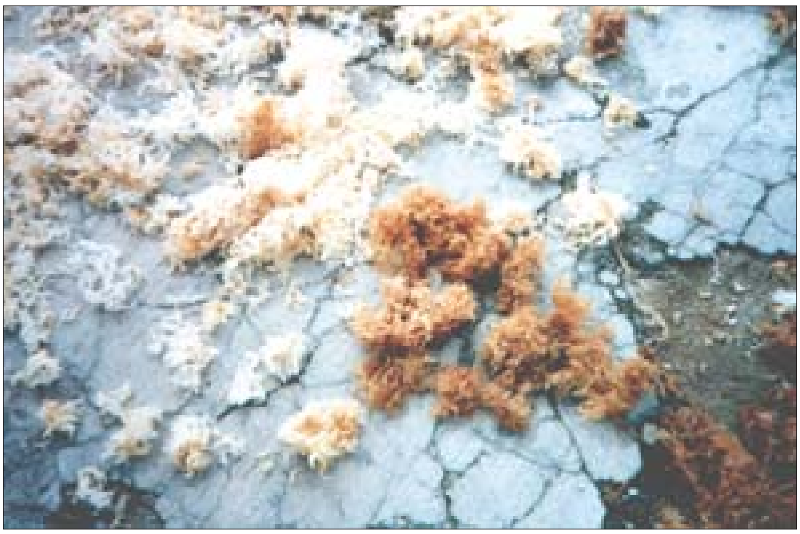
The definitions of the vertical zones of the shore, littoral fringe, eulittoral and sublittoral were given in Section 2.2.

Kappaphycus alvarezii (Figures 33 and 34) is found in the upper part of the sublittoral zone, from just below the low tide line, of reef areas on sandy-corally to rocky substrates where water flow is slow to moderate.

FIGURE 33
Fresh *Kappaphycus alvarezii.*

FIGURE 34
Dried *Kappaphycus alvarezii.*

FIGURE 35
***Betaphycus gelatinum* drying (Hainan Island, China).**



Eucheuma denticulatum thrives on sandy-corally to rocky substrates in areas constantly exposed to moderate to strong water currents.

Betaphycus gelatinum (Figure 35) grows on rocky, coralline substrates, a few metres from the reef-edge, where it is exposed to strong wave action and turbulence.

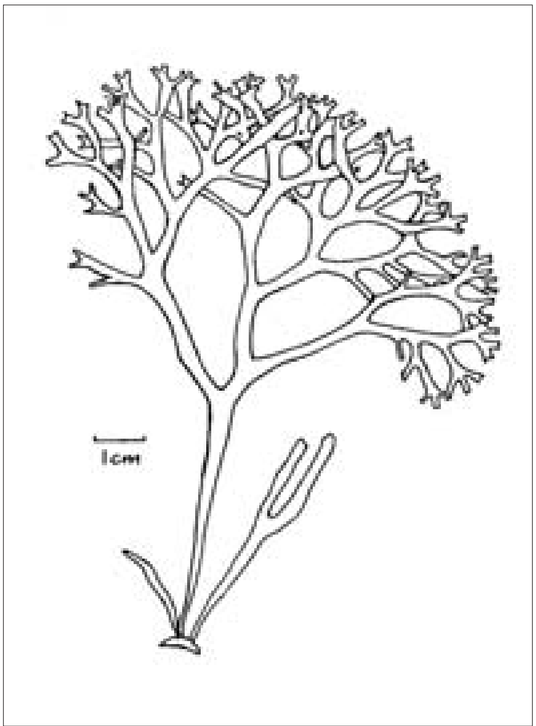


FIGURE 36
Chondrus crispus. **(after Hansen, Packard and Doyle, 1981).**

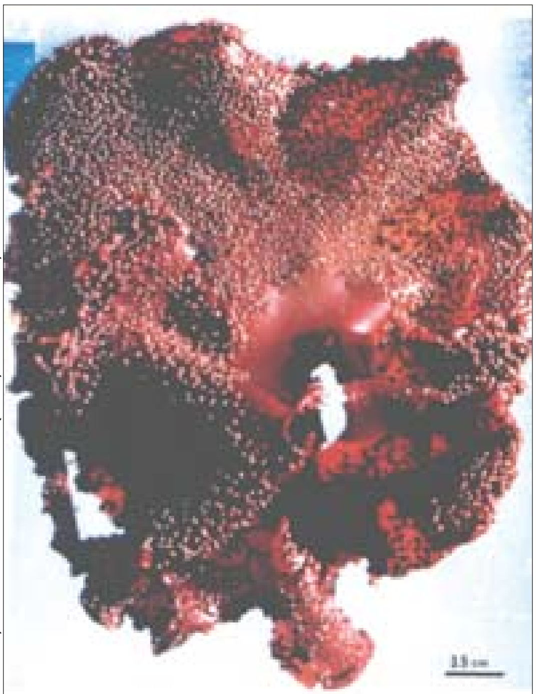


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FIGURE 37
Gigartina skottsbergii

All three require water temperatures of 21°C or more and they thrive in bright light.

Chondrus crispus (Figure 36) grows from the littoral fringe to 20 m below mean low water, depending on the wave motion, transparency and rocky structures available. Usually it is most abundant from mean low water to the mid-sublittoral zone. It grows best on stable rock ledges and large boulders, preferring horizontal shelves, growing not so well on smaller rocks or sediment-covered rocks. Strongest growth is in late spring and summer; least growth is in winter.

Gigartina skottsbergii (Figure 37) grows in the sublittoral at depths of 9–15 m. It grows best in the summer.

Sarcothalia crispata is found from the eulittoral to the sublittoral, down to a depth of 10 m.

Mazzaella laminaroides grows in the eulittoral zone on wave-exposed sites, also in estuaries. Where people collect intertidal gastropods (potential algal grazers), the growth of *Mazzaella laminaroides* flourishes.

Gigartina canaliculata and *Hypnea musciformis* grow in the eulittoral zone.

6.3 SOURCES OF CARRAGEENOPHYTES

Kappaphycus alvarezii and *Eucheuma denticulatum* were originally harvested from natural stocks growing in Indonesia and the Philippines. In the 1970s, cultivation began in both countries and this now supplies most of these species, with only small quantities being collected from the wild. Cultivation has spread to other countries, most successfully in Tanzania (Zanzibar), Viet Nam and some of the Pacific Islands, such as those of Kiribati. Wild *Betaphycus gelatinum* is harvested mainly in Hainan Island, China, Taiwan Province of China and the Philippines, and it is cultivated on Hainan Island.

Chondrus crispus is harvested for carrageenan production in Canada (Nova Scotia and Prince Edward Island), United States of America (Maine and Massachusetts) and France.

Gigartina skottsbergii, *Sarcothalia crispata* and *Mazzaella laminaroides* are all harvested from natural resources in Chile, mainly central Chile from Valparaiso to Chiloe Island.

Some *Gigartina skottsbergii* is also harvested in Argentina.

Gigartina canaliculata is harvested in Mexico (Baja California), and is available from south of Ensenada to Punta San Antonio. *Hypnea musciformis* occurs along most of the coastline of Brazil, but production is erratic in both space and time, increasing the costs of harvesting.

The industry needs about 13 percent of the dry seaweed used annually for production of carrageenan as temperate-water *Gigartina*-like species. These contain lambda carrageenan and a "weak" kappa; the properties of the latter lie between those of a normal kappa (such as obtained from *Kappaphycus alvarezii*) and iota carrageenan. While 1 000–2 000 tonnes come from older sources, such as France and Canada, over 90 percent today comes from Chile. None of the carrageenophytes from Chile is currently cultivated, all come from natural regrowth. Nevertheless there seems to be no evidence of overharvesting and there are areas for expanding the harvest of the most important species, *Gigartina skottsbergii*. This seaweed grows from Puerto Montt to Puenta Avenas. While fishermen are not currently available to harvest along this coastline, an increase in demand would probably stimulate the population shift needed to meet the increase (H.R. "Pete" Bixler, 2002, *pers. comm.*).

6.4 HARVESTING METHODS FOR WILD CARRAGEENOPHYTES

Chondrus crispus has been harvested in Canada since the 1920s, but only came to prominence during the Second World War, when access to Japanese agar stopped and the Irish Moss beds in France also became inaccessible. Production on Prince Edward Island jumped from 5 dry tonnes in 1940 to 900 dry tonnes in 1942. The original collection was from storm tossed seaweed, driven onto the shore by strong winds. Local farmers picked it up from beaches and shores and sometimes waded into the surf with horse-drawn scoops to capture unattached moss. Fishermen took their boats offshore with hand rakes and scrapped the moss from the flat rock shelf where it grew. In the 1970s, large lobster boats equipped with drag rakes and winches were introduced; the steel rakes – about 1 m wide, 25 kg, with about 40 teeth – are dragged across the moss beds. The scale of operation of these boats had a rather severe effect on the regrowth of the beds and perhaps it was fortunate that demand for moss declined sharply as the cultivated *Kappaphycus* and *Eucheuma* became available from the Philippines in the 1980s. With a low demand from carrageenan processors, Irish Moss harvesting has returned to being a part-time fishery, where there is a place for operators equipped with small boats, outboard motors and hand rakes.

For further details of *Chondrus crispus* harvesting in Canada, with very good illustrations of equipment and operations, see Pringle and Mathieson (1986).

Chondrus crispus in France grows mainly around Brittany. However, there are no flat beds, as found in Canada, so the use of dredgers is not possible, only manual gathering. Harvesting is a part-time operation by about 3 000 people, although this number and the harvest are both falling as the living standards of the harvesters rise.

Betaphycus gelatinum on Hainan Island, China, is most abundant about 1 m below the low tide mark and was collected by hand, but cultivation has overtaken this practice.

Gigartina canaliculata grows in the eulittoral zone in Mexico and is harvested from May to September by fishermen, who pull it by hand during low tide.

Mazzaella laminaroides is harvested from the eulittoral zone by people walking around the rocks at low tide and pulling the seaweed from the rocks by hand.

Sarcothalia crispata is harvested from the sublittoral zone by fishermen who dive and use hooks to drag the seaweed off the rock and store it in bags called *chinguillos* while they work.

Gigartina skottsbergii is harvested from the lower sublittoral zone in the same way as *Sarcothalia crispata.* Depending on the area where they dive, each fisherman is able to harvest about 70 kg/hour from a natural bed.

6.5 CULTIVATION OF CARRAGEENOPHYTES

Kappaphycus and *Eucheuma* are both cultivated by the same methods, the two most popular being the fixed, off-bottom line method and the floating raft method.

The basics of the fixed, off-bottom line method are simple. First choose a suitable site, then drive two wooden stakes, about 5–10 m apart, into the bottom. Stretch either a monofilament nylon line or a polypropylene rope between the stakes; the line should be 20–30 cm above the sea bottom and the water must be deep enough to ensure that the seaweed is not exposed at low tide. Small pieces of seaweed (50–100 g) are tied to the line. Many of these lines are constructed, usually 1 m apart (Figure 38). If the site is suitable and farming maintenance is carried out regularly, the seaweed should reach 10 times its original size in 6–8 weeks, when it can be harvested. It is sun dried away from sand and dirt, then packed into bales ready for shipping.

The main factor determining success or failure is choosing a suitable site. If *Kappaphycus* or *Eucheuma* is growing naturally, the place is probably suitable. If not, the following criteria apply.

- Reefs, well away from any freshwater sources (small rivers, etc.), have proven to be good sites. If the seawater salinity (usually 35 parts of salt per 1 000 parts of water (parts per thousand = ppt)) falls below 30 ppt, the seaweed does not grow well.
- Water temperature should be 25–30°C; in shallow water near the beach, the water temperature may become too high during the day; a good site is between the low tide limit and the reef edge.
- The seaweed obtains its nutrients for growth from the water so water movement through the seaweed is important. Moderate water movement is preferable; this also helps to stabilize water temperature and salinity. If the current is too strong it can cause pieces of the growing plant to break off and be lost; wave action must be avoided for the same reason.
- The sea bottom type is important; a white, firm bottom with a limited amount of natural seaweed is good, too much seaweed or sea grass will compete for nutrients with the cultivated seaweed. Silt or mud on the bottom indicates possible poor water

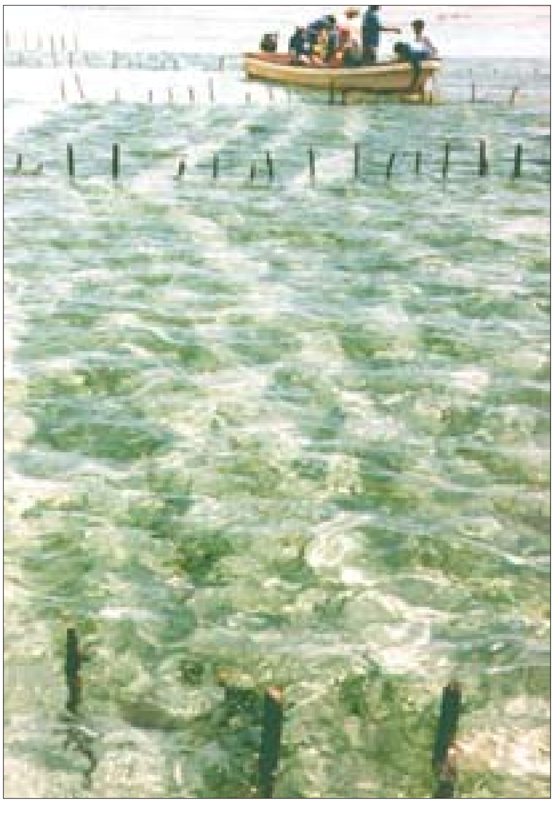


FIGURE 38
***Kappaphycus alvarezii* cultivation using fixed, off-bottom lines (Kiuva, Fiji).**

flow and if the silt is disturbed it may settle on the plants; muddy water will also reduce the light available to the seaweed.

- Plenty of sunlight is necessary for good growth; seaweed planted in shallow water (30–50 cm) grows well; in deeper water (more than 1 m) the light is reduced and growth is poor. Water depth is also important for farming: 0.5–1.0 m depth at low tide is good for the seaweed and allows the farmer to carry out maintenance more easily.
- Regular maintenance is essential. It consists of removing other seaweeds growing either on the lines or the crop itself, removing poorly growing plants, replacing lost plants, and making any necessary repairs to the stakes and lines.

Once a site has been chosen, a trial is made using the chosen species. A few lines are set out at each of several different parts of the site, small pieces of the seaweed are attached and their growth rate is monitored weekly. If after 2–3 months the daily growth rate is 3–5 percent, the site is probably suitable and a small farm can be established. Because of the larger capital outlay required for large installations, before venturing into large farms it is advisable to monitor conditions for a full year so that the effects of all weather and other ecological factors are known. Small family farms have been the most successful, partly because there is more incentive to provide the necessary care and maintenance to the farm they own rather than one owned by an employer.

Various problems can arise. Grazing fish can damage the crop. Siganids (rabbitfish) and puffers are common pests. Siganids are the most destructive, especially if the plants are all small: the entire crop can be devoured and even dense beds can be severely damaged. There is no simple solution except to move to another site where they are not prevalent. Turtles pose a special problem: they obviously take large bites but they also crawl through a farm, causing devastating physical damage. Long-spined sea urchins are also a pest, and can cause injury to the farmer as they try to remove them. The most common symptom of bad health is *ice-ice,* so named because of the white segments that appear on the plants, causing them to break at that point. There is some disagreement about its cause: some say it is a symptom of a bacterial or viral infection, others attribute it to physical stress caused by changes in the environment in which it is growing. Storms lead to strong water movement that can cause plants to break apart and even cause physical damage to the lines and stakes. So localities that are subject to seasonal cyclones, etc., should be avoided, or precautions taken during the periods – usually about 3 months of the year – when bad weather can be expected.

The materials required include the wooden stakes used to hold the lines, which can be made from mangrove timbers or any other timber that can withstand immersion in seawater for at least a year; they need to be 5–10 cm diameter, sharpened at one end (Figure 39) and driven into the bottom until held very firmly. Monofilament

FIGURE 39
Stakes from mangrove trees for use with fixed, off-bottom lines.

FIGURE 40
Fixing "tie-ties" to seedlings, using 20–25 cm pieces of blue plastic raffia.

nylon line with a breaking strain of 90 kg (200 lb) is used to support the seaweed, or 3 mm diameter polypropylene rope. The rope has an advantage in that the string used to tie the seaweed to the line can actually be inserted through the twist of the rope, ensuring it does not slide along the rope. The seaweed is tied to the line with a soft synthetic string, often called a "tie-tie", preferably using a slip knot so that the seaweed can be easily removed at harvest time. The seedlings, 50–150 g pieces obtained from the last harvest or the nearest farm, are prepared by fixing the tie-ties to them (Figure 40), ensuring that they are kept moist all the time that they are not in the water. Seedlings and tie-ties are then fixed to the ropes at 20–25 cm intervals (Figure 38), the ropes can already be in the water attached to the stakes or it can be done on the land and the ropes then stretched between the stakes. At harvest time, the whole plant is removed and new seedlings are cut from the tips.

To maintain the value of the crop, careful post-harvest treatment is necessary. It must be kept away from sand and dirt, so drying racks or mats are used (Figure 41). In some areas, the entire line is removed from the sea and hung over a tall "fence" to allow drying, the seaweed being untied after it has dried. In most areas, sun drying for about 2–3 days is sufficient to reduce the moisture content to the required 35 percent level. With practice, farmers can estimate the moisture level by feeling the seaweed, by its firmness and how it bends. If the moisture is above 40 percent the seaweed may rot during storage and transport; below 35 percent the seaweed becomes too firm and bouncy and it is difficult to compress it into bales. During drying, white salt-like crystals appear on the outside

FIGURE 41
Drying *Kappaphycus alvarezii.*

FIGURE 42
A raft for use in the floating-raft method of cultivation.

of the seaweed; any that are loose and can be shaken off are removed. Buyers do not like damp seaweed, nor foreign matter such as sand, dirt, stones, coral pieces or excessive salt. Some less scrupulous farmers have been known to add salt to the dried product since they are paid by weight and salt is cheaper than seaweed.

The second method of cultivation is the floating raft method. This is suitable in protected areas where water current is weak or where the water is too deep for fixed bottom lines. The selected areas must meet the criteria previously described, at least as they apply to this situation, and trials should be conducted in the same way. A white, silt-free bottom is not necessary. A floating construction is used to suspend the seaweed about 50 cm below the surface. Often a 3×3 m square timber frame, made from bamboo or mangrove timber, is used with 3 mm polypropylene ropes stretched parallel in one direction between the timbers, at 10–15 cm intervals (Figure 42). The seedlings are tied to the ropes and the raft is anchored to the bottom. The anchor ropes may need to hold the raft below the surface at the beginning, but as the plants grow and add weight to the raft, it may need extra support (such as polystyrene foam boxes tied to the corners of the raft) to prevent it sinking too low in the water. The seedlings can be tied to the raft on land and the raft towed into position. Regular maintenance during growth is still required. At harvest time the entire raft can be removed and used as a drying rack by suspending it between four corner supports, such as large drums.

The off-bottom line farming method allows easier access since the farmer can walk around the lines at low tide, but the floating rafts have the advantage that they can be easily moved to another position if necessary, and removed from the water altogether in bad weather, thus avoiding destruction by heavy seas and strong winds.

For further details

Methods and illustrations can be found in Trono (1993) and its associated CD-ROM, Critchley and Ohno (1997). For a thorough discussion of cultivation and some of its associated problems see Doty (1986), who also examines some of the costs and returns from farming.

Very practical guides to *Eucheuma* and *Kappaphycus* cultivation, with useful illustrations, can be found in Foscarini and Prakash (1990) or Ask (1999).

Foscarini and Prakash (1990) is written for the person actually setting up a farm, written simply but carefully, and answers questions such as:

- How much will it cost to start seaweed farming?
- How can I organize my work at the farm?
- What should I do to maintain my farm?
- What records do I need to keep?

- How much will I earn from my seaweed farm?

Copies are available upon request from the FAO David Lubin Library (see reference for details).

Ask (1999) is similar, and copies may be available from the author (see references).

Similar guides may be available from other carrageenan producers, listed in Section 7.2.

In Viet Nam, *Kappaphycus* is being cultivated in offshore areas using floating rafts, in lagoons and inlets using fixed off-bottom monolines, and it is the only country to date that has also used ponds for *Kappaphycus*. Fixed off-bottom monolines and fixed off-bottom nets have been used in ponds with muddy bottoms, while broadcasting seedlings directly onto the bottom is used where the bottom is sandy or coralline. Sometimes the ponds are used for seaweed for six months and then rotated with shrimp for six months.

Betaphycus gelatinum is cultivated on Hainan Island, China. Pieces of wild seaweed are fastened to coral branches with rubber rings and thrown onto sublittoral reefs, where divers rearrange them. Some long-line cultivation has also been used.

In France, one company cultivated *Chondrus crispus* in raceways and found it an economic proposition from 1978 to 1996. Its success was related to the selection of a fast-growing strain and an automated system that together produced a growth rate ten times faster than the natural rate. However, by 1996, the cost of wild *C. crispus* had fallen and the operation was no longer considered economic.

Methods for the cultivation and restocking of *Gigartina skottsbergii* have resulted from collaboration between the Division of Aquaculture, Instituto de Fomento Pesquero, and the Department of Oceanography, Universidad de Concepción, Chile, and have been published as Romo, Ávila and Candia (2001).

Cultivation methods for *Sarcothalia crispata* are being developed.

6.6 QUANTITIES HARVESTED

About 120 000 dry tonne/year is harvested of *Kappaphycus alvarezii*, mainly from the Philippines, Indonesia and Tanzania (Zanzibar). For *Eucheuma denticulatum*, the harvest is around 30 000 dry tonne/year, again mainly from the same countries. About 300 dry tonne/year of *Betaphycus gelatinum* is harvested yearly from Hainan Island, mainly from cultivation.

Until the early 1970s, *Chondrus crispus* was the main source of carrageenan and Canada provided about 70 percent of the world production. By 1992, with the success of cultivation of *K. alvarezii* and *E. denticulatum,* the demand for *C. crispus* had fallen to 3.8 percent of the total requirement for carrageenophytes, and of this, Canada supplied only 12 percent. In 1992, only about 7 000 wet tonnes was harvested, compared with the peak production of 50 000 wet tonnes in 1974. In France, there has also been a decline in harvesting, from about 6 000 wet tonnes in 1975 to about 3 000 wet tonnes in 1996.

The *Gigartina skottsbergii* harvest in Chile was 30 100 wet tonnes in 2000. The *Gigartina canaliculata* in Mexico has fallen from a maximum production of 1 100 dry tonnes in 1978 to 200 dry tonnes, and it is all exported. Small quantities of other species are collected from Mexico, Morocco and Peru.

Table 7 summarizes estimates of harvests of carrageenophytes, all in dry tonness.

TABLE 7
Carrageenophyte resources, tonnes dry weight (2001)

Chondrus		
Canada	2000	
France, Spain and Portugal	1 400	
Republic of Korea	500	
Subtotal	3 900	2.3%
Eucheuma and *Kappaphycus*		
Indonesia	25 000	
Philippines	115 000	
Tanzania (Zanzibar)	8 000	
Others	1 000	
Subtotal	149 000	88.5%
Gigartina		
Chile	14 000	
Morocco, Mexico and Peru	1 500	
Subtotal	15 500	9.2%
Total	168 400	100%

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

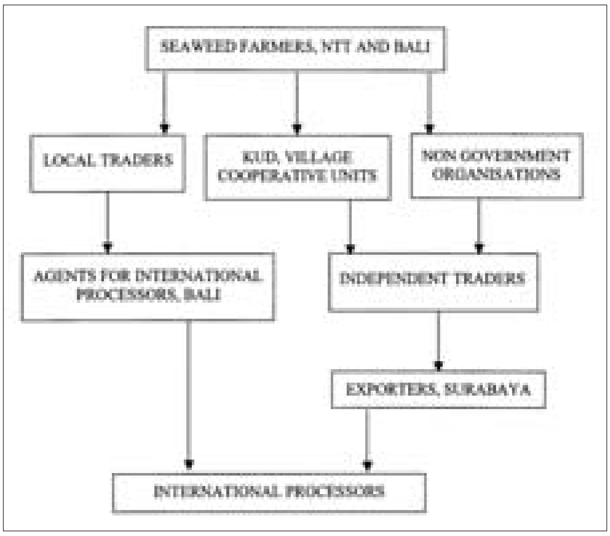


FIGURE 43
Marketing channel for seaweed – Indonesia (Burges Watson, 1999).

6.7 MARKETS

For *Kappaphycus* and *Eucheuma*, the farmers usually sell to middlemen; sometimes there may be two in the chain. They sort and clean up the seaweed before selling it on to the carrageenan processors. The middlemen frequently help to finance the farmers with loans for equipment and seedlings. As cultivation in the Philippines has developed, some of the major processors have set up extraction factories there, eliminating the former transport costs to Europe. Two distinct grades of carrageenan are produced: refined and semi-refined. Large quantities of seaweed produced in the Philippines are now processed there, producing all grades of carrageenan.

In Indonesia, again, there are active middlemen and a few local companies making semi-refined carrageenan (SRC). Figure 43 shows the marketing chain for *Kappaphycus* in Indonesia, and this is also typical of the situation in other countries, such as the Philippines. A large proportion of the seaweed is exported to Japan and the Republic of Korea. In Zanzibar (Tanzania) all the production is exported, mainly to the companies who helped to establish the industry. Pacific nations such as Kiribati have a transport cost problem but have entered into contracts with at least one major producer who is willing to pay a fixed price if the supply is assured. The farmgate price of these seaweeds has undergone severe fluctuations in the past, with boom and bust cycles that are harmful to both buyer and seller in the long term. Fixed price contracts assure the farmers of a steady income, otherwise when the farm gate price falls too low they simply abandon seaweed farming and return to fishing and other activities that sustain a subsistence living. This eventually leads to a shortage, a demand that cannot be met, giving rise to increased prices. In Chile there is large internal consumption by four processors; the remainder is exported through several intermediary companies. A useful review of trends of seaweed production in Chile includes a diagram showing the marketing channels within Chile (Norambuena, 1996). All the *Betaphycus gelatinum* produced in China is used there. In France, all *Chondrus* harvested is used locally. Canadians operate fishermens' cooperatives that sell *Chondrus* to FMC Biopolymer, based in nearby Maine, and also export to Europe.

6.8 FUTURE PROSPECTS

Demand for carrageenan has risen at a steady rate of about 5 percent annually, and this should continue for several years as a continuing increase in demand is forecast. Carrageenan extractors actively pursue a policy of assistance to those interested in establishing seaweed farms, so future prospects for the industry are very encouraging.

7. Carrageenan

There are several carrageenans, differing in their chemical structure and properties, and therefore in their uses. The carrageenans of commercial interest are called iota, kappa and lambda.

Their uses are related to their ability to form thick solution or gels, and they vary as follows.

Iota	Elastic gels formed with calcium salts. Clear gel with no bleeding of liquid (no synaeresis). Gel is freeze/thaw stable.
Kappa	Strong, rigid gel, formed with potassium salts. Brittle gel forms with calcium salts. Slightly opaque gel, becomes clear with sugar addition. Some synaeresis.
Lambda	No gel formation, forms high viscosity solutions.

The carrageenan composition in red seaweeds differs from one species to another.

Chondrus crispus	mixture of kappa and lambda.
Kappaphycus alvarezii	mainly kappa.
Eucheuma denticulatum	mainly iota.
Gigartina skottsbergii	mainly kappa, some lambda.
Sarcothalia crispata	mixture of kappa and lambda.

7.1 CARRAGEENAN PRODUCTION METHODS

There are two different methods of producing carrageenan, based on different principles.

In the original method – the only one used until the late 1970s–early 1980s – the carrageenan is extracted from the seaweed into an aqueous solution, the seaweed residue is removed by filtration and then the carrageenan is recovered from the solution, eventually as a dry solid containing little else than carrageenan. This recovery process is difficult and expensive relative to the costs of the second method.

In the second method, the carrageenan is never actually extracted from the seaweed. Rather the principle is to wash everything out of the seaweed that will dissolve in alkali and water, leaving the carrageenan and other insoluble matter behind. This insoluble residue, consisting largely of carrageenan and cellulose, is then dried and sold as semi-refined carrageean (SRC). Because the carrageenan does not need to be recovered from solution, the process is much shorter and cheaper.

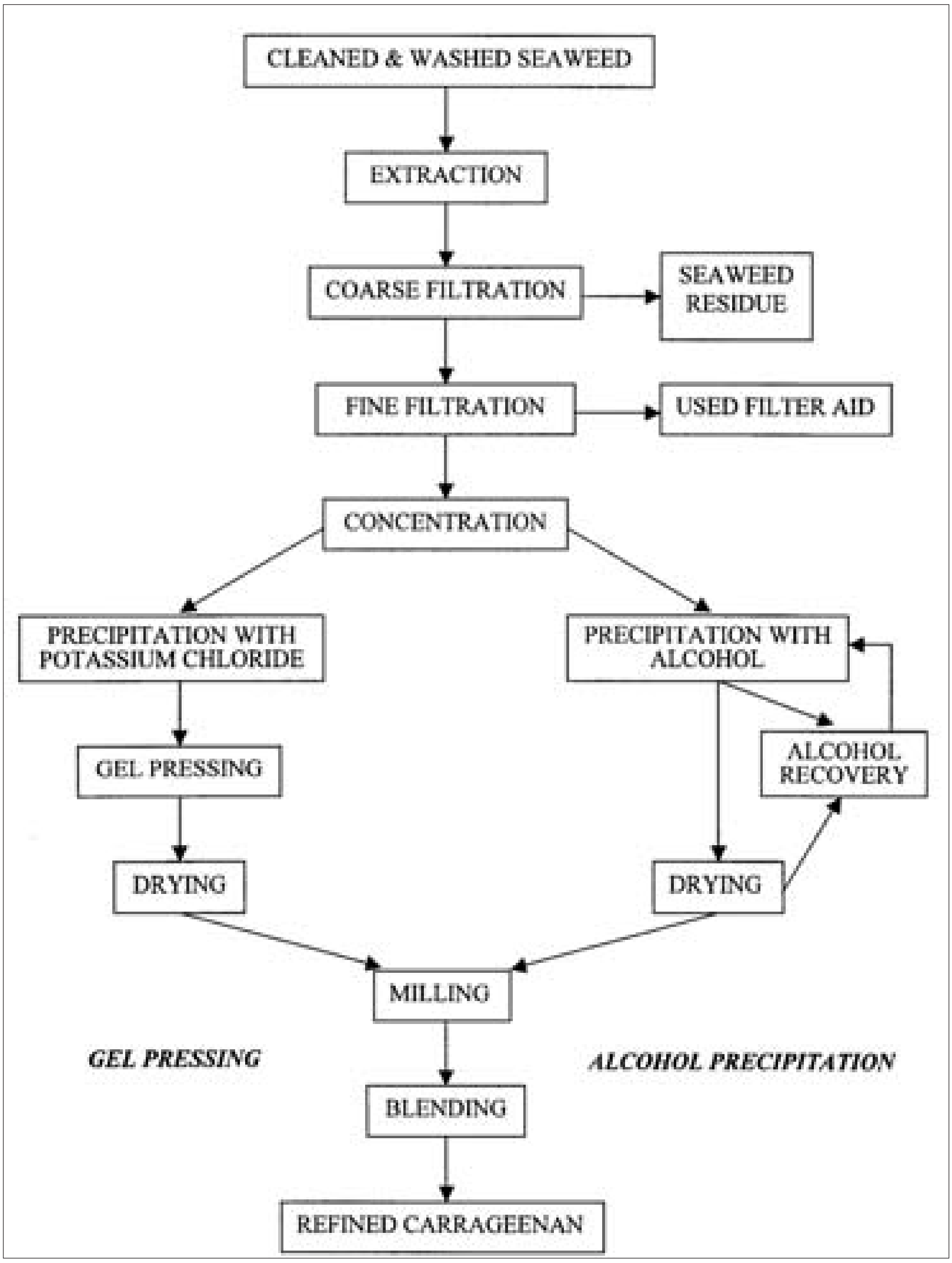
7.1.1 Refined carrageenan and filtered carrageenan

Refined carrageenan is the original carrageenan and until the late 1970s–early 1980s was simply called carrageenan. It is now sometimes called filtered carrageenan. It was first made from *Chondrus crispus,* but now the process is applied to all of the above algae.

The seaweed is washed to remove sand, salts and other foreign matter. It is then heated with water containing an alkali, such as sodium hydroxide, for several hours, with the time depending on the seaweeds being extracted and determined by prior small-scale trials, or

FIGURE 44
Sun drying semi-refined carrageenan (alkali treated *K. alvarezii*).

FIGURE 45
Flow chart for the production of refined carrageenan (after Porse, 1998).



experience. Alkali is used because it causes a chemical change that leads to increased gel strength in the final product. In chemical terms, it removes some of the sulphate groups from the molecules and increases the formation of 3,6-AG: the more of the latter, the better the gel strength. The seaweed that does not dissolve is removed by centrifugation or a coarse filtration, or a combination. The solution is then filtered again, in a pressure filter using a filter aid that helps to prevent the filter cloth becoming blocked by fine, gelatinous particles. At this stage, the solution contains 1–2 percent carrageenan and this is usually concentrated to 2–3 percent by vacuum distillation and ultrafiltration.

The processor now has a clear solution of carrageenan and there are two methods for recovering it as a solid, both rather similar to those described previously for agar production. An alcohol-precipitation method can be used for any of the carrageenans. A gel method can be used for kappa-carrageenan only, and the gel can be dehydrated either by squeezing or by subjecting it to a freeze-thaw process.

In the alcohol method, isopropanol is added until all the carrageenan is precipitated as a fibrous coagulum that is then separated using a centrifuge or screen (a fine sieve). The coagulum is pressed to remove solvent and washed with more alcohol to dehydrate it further. It is then dried and milled to an appropriate particle size, 80 mesh or finer. For the process to be economic the alcohol must be recovered, both from the liquids and the dryer, and recycled.

The gel method relies on the ability of kappa carrageenan to form a gel with potassium salts. The gel may be formed in various ways. For the freeze-thaw process it is convenient to form it as spaghetti-like pieces by forcing the carrageenan solution through fine holes into a potassium chloride solution. The fine "spaghetti" is collected and washed with more potassium chloride to remove more water, pressed to remove surplus liquid and then frozen. When allowed to thaw, separation of water occurs by synaeresis, the pieces are washed with more potassium chloride, chopped up and dried in a hot air dryer. Inevitably the product contains some potassium chloride. The alternative to freeze-thaw is to force water out of the gel by applying pressure to it, using similar equipment to that used for agar (Figure 10). After squeezing for several hours the sheets of gel are chopped, dried in a hot air dryer and milled to an appropriate particle size. Many agar processors are now using their equipment and similar techniques to produce kappa carrageenan as well.

Figure 45 summarizes the above processes.

7.1.2 Semi-refined carrageenan and seaweed flour

Semi-refined carrageenan (SRC) was the name given to the product first produced by the second method of processing noted in Section 7.1. This is the method in which the carrageenan is never actually extracted from the seaweed.

In the production of SRC, *Kappaphycus alvarezii*, contained in a metal basket, is heated in an alkaline solution of potassium hydroxide for about two hours. The hydroxide part of the reagent penetrates the seaweed and reduces the amount of sulphate in the carrageenan, increases the 3,6-AG so the gel strength of the carrageenan in the seaweed is improved. The potassium part of the reagent combines with the carrageenan in the seaweed to produce a gel and this prevents the carrageenan from dissolving in the hot solution. However, any soluble protein, carbohydrate and salts do dissolve and are removed when the solution is drained away from the seaweed. The residue, which still looks like seaweed, is washed several times to remove the alkali and anything else that will dissolve in the water. The alkali-treated seaweed is now laid out to dry; in hot climates, like the Philippines, usually on a large concrete slab (Figure 45). After about two days it is chopped and fed into a mill for grinding to the powder that is sold as SRC or seaweed flour.

The above process is summarized in Figure 46 (seaweed flour branch).

However, the seaweed flour is coloured, often has a high bacterial count and is not suitable for human consumption. Nevertheless it immediately found a large market in canned pet food because it is a good gelling agent and was so much cheaper than refined

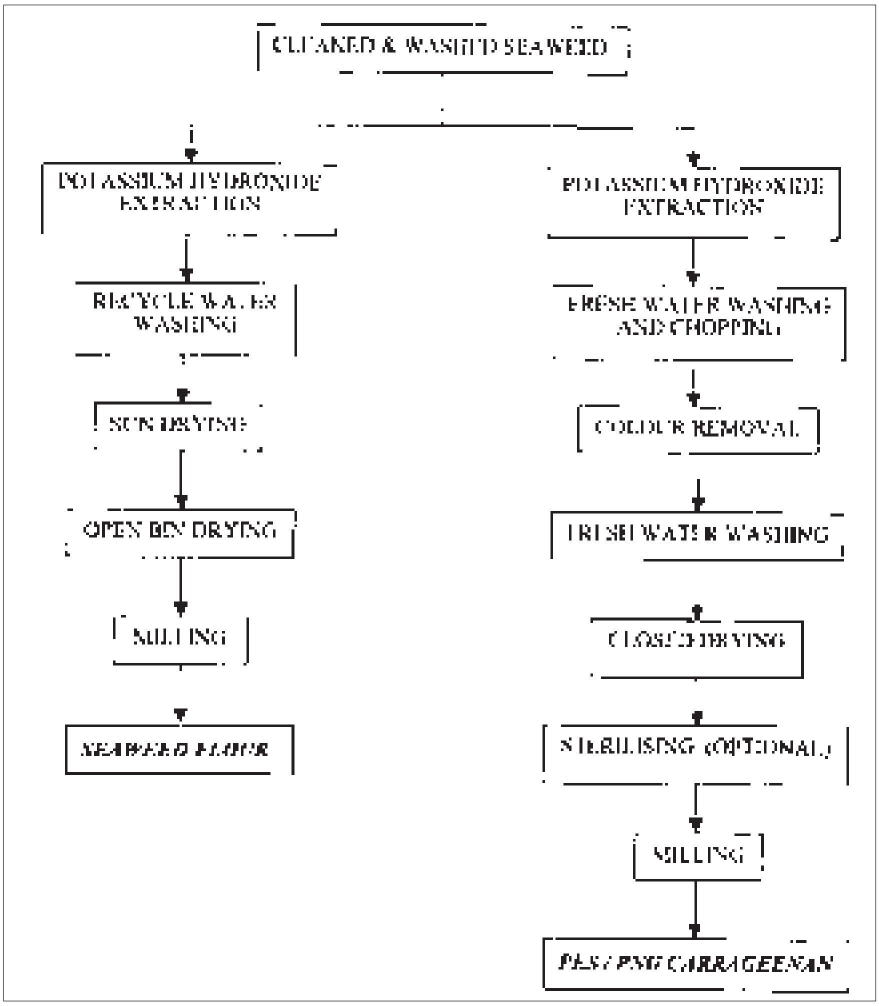


FIGURE 46
Flow chart for the production of seaweed flour and PES/PNG carrageenans (after Bixler, 1996).

carrageenan. The temperatures used in the canning process destroy any bacteria so the high bacterial count in the SRC is not a problem. Sometimes the dried product is just chopped into pieces, not milled, and sold as a raw material to refined carrageenan processors. It is called alkali treated cottonii (ATC) or alkali treated cottonii chips (ATCC), or even simply cottonii chips. If this treatment is done in the country of origin of the seaweed, such as the Philippines or Indonesia, this means processors in Europe and United States of America have cheaper transport costs per tonne of carrageenan, compared with shipping dried seaweed. They have also left behind some waste products, which reduces their waste treatment costs.

Kappaphycus alvarezii is used in this process because it contains mainly kappa carrageenan and this is the carrageenan that forms a gel with potassium salts. Iota-containing seaweeds can also be processed by his method, although the markets for iota carrageenan are significantly less than those for kappa. Lambda carrageenans do not form gels with potassium and would therefore dissolve and be lost during the alkali treatment.

The simplicity of the process means the product is considerably cheaper than refined carrageenan.

There is no alcohol involved that must be recovered, no distillation equipment to purify alcohol, no equipment for making gels, no refrigeration to freeze the gels, nor any expensive devices to squeeze the water from the gel.

7.1.3 Philippine natural grade (PNG) and processed *Eucheuma* seaweed (PES)

Producers in the Philippines developed a higher quality product, suitable for human consumption, by modifying the process just described for SRC.

After the alkali treatment and water washing, the product is chopped and treated with bleach to remove the colour (chopping improves penetration by the bleach, and bleach also helps to reduce the bacterial count). After washing to remove any bleach, the product is dried in a closed dryer. In this type of dryer, indirectly heated hot air passes up through a bed of the unground pieces or chips that are being carried through the dryer on a chain-type belt. This closed system dryer is usually sufficient to keep the bacterial count low enough to make a human-food grade product. If bacteria reduction is required, the dried chips can be milled and then washed with alcohol (ethanol) followed by vacuum evaporation to recover the alcohol. A simpler process is to treat the milled powder with superheated steam.

The above process is summarized in Figure 46 (PES/PNG carrageenan branch).

The product was originally called Philippine natural grade carrageenan (PNG).

Attempts to market this product as food grade in the United States of America and Europe resulted in strong opposition from the producers of refined carrageenan who did not wish to lose market share to this cheaper product. Eventually in the United States of America, the Food and Drug Administration declared it suitable for use in human food and to be labelled as “carrageenan”, the same status as that of the refined product.

In Europe, both refined and PNG are permitted in human food, but carry different labels:

- refined carrageenan is labelled “carrageenan” and E-407; while
- Philippine natural grade is labelled “processed *Eucheuma* seaweed” or “PES”, and E-407a.

So PNG and PES are the same grade of carrageenan.

The main difference between refined carrageenan and PNG is that PNG contains the cellulose that was in the original seaweed while in refined carrageenan this has been removed by filtration during the processing. Refined carrageenan will therefore give a clear solution, while PNG gives a cloudy solution. Where clarity of a user’s product is of no consequence, PNG is suitable.

For further details

Detailed information on any methods of carrageenan extraction are not easy to find. As Stanley (1987) said, they are closely guarded as trade secrets by the several manufacturers. Some information can be found in Stanley (1987), Stanley (1990) and Therkelsen (1993).

7.2 CARRAGEENAN PRODUCERS AND DISTRIBUTORS

A summary of the capacity of carrageenan producers according to their broad geographical location is given in Table 8, and the principal producers and distributors are listed in the next section.

TABLE 8

Carrageenan processors. Capacity in tonnes (2001)

	Alcohol process	Gel process	PES	Total	%	ATC[1]
Europe	8 100	5 000	500	13 600	32	
Americas	4 700	3 350	1 100	9 150	21	
Asia-Pacific	2 000	8 280	9 900	20 180	47	16 000
Total	14 800	16 630	11 500	42 930		16 000

[1] ATC = Alkali treated cottonii or seaweed flour, used mainly for pet food.
Source: H. Porse, CP Kelco ApS, 2002, *pers. comm*.

7.2.1 Refined carrageenan producers and distributors

CP Kelco ApS
Ved Banen 16
4623 Lille Skensved
Denmark
Tel: [INT+45] + 5616 5616
Fax: INT+45] + 5616 9446
Website: www.cpkelco.com

Shemberg Marketing Corporation
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Cebu City
The Philippines
Tel: [INT+63] + (32) 346 0866
Fax: [INT+63] +(32) 346 1892; 346 0863

Shemberg Biotech Corporation
Carmen, Cebu City
The Philippines
Tel: [INT+63] + (32) 254 9380
Fax: [INT+63] + (32) 254 9388

Ingredients Solutions Inc.
PO Box 407
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Fax: [INT+1] + (207) 548 2921

Marcel Carrageenan Corporation
926 Araneta Avenue
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Philippines
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Fax: [INT+63] + (2) 712 1989/5879

FMC Biopolymer
1735 Market Street
Philadelphia PA 19103
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Fax: [INT+1] + (215) 299 5809
Websites: www.fmc.com;
www.fmcbiopolymer.com

Degussa Texturant Systems
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Website: www.daniscocultor.com

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Fax: [INT+33] 1 53 56 55 55
Website: www.rhodiafood.com

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Fax: [INT+56] + 2 232 1544

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Fax: [INT+34] + (986) 336 621
Website: www.ceamsa.com

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Polígono de Villalonquejar
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Fax: [INT+34] + (947)298518
Website: www.hispanagar.net

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Fax: [INT+81] + (3) 3235 8863

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

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

Chuo Food Materials Co.Ltd
Osaka
Japan

Marine Science Co Ltd
Higashi-kanda Towa-building 6F , 2-3-3,
Higashi-kanda
Chiyoda-ku
Tokyo 101-0031 Japan
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Fax [INT+81] + (3) 3865 3450

7.2.2 PNG and PES and seaweed flour producers and distributors

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Fax: [INT+1] + (207) 548 2921

Marcel Carrageenan Corporation
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The Philippines
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Fax: [INT+63] + (2) 712 1989/5879

Shemberg Marketing Corporation
corner Lapu-lapu and Osmena Boulevard
Cebu City
The Philippines
Tel: [INT+63] + (32) 346 0866
Fax: [INT+63] + (32) 346 1892/0863

Quest International Philippines Corp.
Mactan Export Processing Zone,
G/F SFB Pt. 1,
Lapu-Lapu City
Cebu
The Philippines.
Tel: [INT+63] + (32) 340 0322/0319/0764
Fax: [INT+63] + (32) 340 0328/0324

FMC Corporation
Ouano Compound
Looc, Mandaue City
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Fax: [INT+63] + (32) 54098, 3461182/1187

Geltech Hayco, Inc.
2211 Taft Avenue
Metro Manila
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Fax: [INT+63] + (2) 526 0591

TBK Manufacturing Corp.
Brgy 76, Hollywood, Nula-tula
Tacloban city
6500 Leyte
The Philippines
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Fax: [INT+63] + (2) 725 5163

Iberagar S.A.
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Coina
Portugal
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Fax: [INT+35] + (121) 2109255
Website: www.iberagar.com

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Tel: [INT+62] + (31) 548 2003
Jakarta office:
Tel: [INT+62] + (21) 564 7270
Fax: [INT+62] + (21) 564 9285

C.V. Cahaya Cemerlang
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Fax: [INT+62] + (411) 31 82 27

P.T. Gumindo Perkasa Industri
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Jln Jend Gatal Kav 6-7
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For further information about the Philippines contact:

Secretary General
Seaweed Industry of the Philippines
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Osmena Blvd
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The Philippines
Tel: [INT+62] + (32) 253 7433
Fax: [INT+62] + (32) 254 8780

For further details about Indonesia and other Indonesian companies contact:
Indonesian Seaweed Industry Association (APBIRI) at:

Asosiasi Pengusaha Budidaya dan Industri Rumput Laut Indonesia (APBIRI)
BPPT Lt. 13
Jl. MH Thamrin No. 8
Jakarta Pusat 10340
Indonesia
Tel: (62) 21 322430

7.3 CARRAGEENAN USES

Before discussing uses, some explanations of the properties of carrageenans are necessary.

Both kappa and iota carrageenan form gels with potassium and calcium salts. Aqueous solutions of both carrageenans must be heated above 60°C for the carrageenan to dissolve, and after addition of the salt, the gel forms as the solution cools. For kappa, as little as 0.5 percent in water and 0.2 percent in milk is sufficient to form gels.

Kappa forms gels most strongly with potassium salts, followed by calcium salts. Potassium gives a rigid, elastic gel while calcium produces a stiff, brittle gel. Kappa gives the strongest gels of all carrageenans, but they are also the ones most likely to bleed (most subject to synaeresis). This liability can lessened in a couple of ways. If iota and lambda carrageenans are blended in with the kappa, bleeding can be reduced, so will also the rigidity and brittleness of the gel; however, the gel strength may also be lowered. Synaeresis can also be reduced by adding locust bean gum (obtained from the seeds of the carob tree (*Ceratonia siliqua*), growing in Spain, Italy, Cyprus, etc.). This gum also allows the amount of kappa to be reduced while still maintaining the same gel strength. The kappa can be reduced to one-third of the concentration that would be needed if no locust bean gum were used. The resulting gels are more resilient than those with kappa alone. As long as locust bean gum is cheaper than kappa there is also an economic advantage. However, the cost of locust bean gum can fluctuate depending on the harvest and demand.

Iota forms gels most strongly with calcium salts, followed by potassium salts – the reverse of kappa reactivities. Calcium gels are soft and resilient and are virtually free of bleeding. They can be frozen and thawed without destroying the gel. They show an unusual property for a gel: thixotropic flow; this means the gel can be stirred and it will flow like a thick liquid, but if left to stand it will gradually reform a gel.

A similar thixotropic behaviour is found with very low concentrations of kappa carrageenan in milk; a weak gel forms that is easily made to flow by shaking. The weak gel is strong enough to suspend fine particles in the milk, such as cocoa in chocolate milk.

Protein reactivity of carrageenans is an important property that is utilized in several applications. Carrageenan molecules carry negative charges; this is what enables them to combine with positively charged particles like the potassium found in potassium salts. They can also combine with positively charged proteins. Carrageenan will combine with the protein in milk (casein) to form a three-dimensional gel network. The exact nature of the interaction of proteins with carrageenans appears to be more complex than this simple explanation, and the interested reader can find more detail in the references suggested in Section 7.3.8.

7.3.1 Dairy products

The main applications for carrageenan are in the food industry, especially in dairy products.

Frequently, only very small additions are necessary, 0.01–0.05 percent. For example, kappa carrageenan (at 0.01–0.04 percent) added to cottage cheese will prevent separation of whey, and a similar amount added to ice cream also prevents whey separation that may be caused by other gums that were added to the ice cream to control texture and ice crystal growth. The cocoa in chocolate milk can be kept in suspension by addition of similar amounts of kappa; it builds a weak thixotropic gel that is stable as long as it is not shaken strongly. Dry instant chocolate mixes, to be mixed with water or milk, can have improved stability and mouth feel using lambda or a mixture of carrageenans.

Lambda or a mixture can also improve liquid coffee whiteners by preventing the separation of fat; these applications require 0.2–0.3 percent additions, but much smaller quantities will prevent fat separation in evaporated milks. Those small containers of UHT sterilized milk found in the refrigerators of some hotels may have kappa added to prevent fat and protein separation. Lambda or kappa may be added to natural cream to help maintain the lightness (incorporated air) if it is whipped. Many more uses in milk and dairy products can be found in the references below.

7.3.2 Water-based foods

With the appearance of bovine spongiform encephalopathy (BSE, or mad cow disease) and foot-and-mouth disease, efforts have been made to find suitable substitutes for gelatin. Gelatin jellies have long been favoured because they melt at body temperature, giving a smooth mouth feel and easy release of flavours. However, if they are stored for a day or two, they toughen and are less pleasant to eat. Gels made from iota carrageenan have the disadvantage of a high melting temperature, so they are not as smooth to eat as gelatin gels. They do not melt on hot days and do not require refrigeration to make them set, so these are advantages in hot or tropical climates, and a further advantage is that they do not toughen on storage. In the last two years there have been several claims by food ingredients companies for products, made from a mixture of hydrocolloids, that imitate the properties of gelatin. Carrageenan producers find that by combining various carrageenans with locust bean gum, konjac flour and starch, they can provide a variety of melting and non-melting gels and gel textures to meet the requirements of most of their clients. Long-life refrigerated mousse desserts, based on carrageenan and pectin rather than gelatin, are suitable for vegetarians and some ethnic groups.

Conventional fruit jellies are based on pectin and a high sugar content to help set the jelly. In a low- or non-calorie jelly the pectin must be replaced, and mixtures of kappa and iota have proved to be suitable. Fruit drink mixes to be reconstituted in cold water contain sugar (or aspartame), acid and flavour. Addition of lambda carrageenan gives body and a pleasant mouth feel. Sorbet is a creamy alternative to ice cream with no fat; use of a mixed kappa and iota together with locust bean gum or pectin provides a smooth texture to the sorbet.

Low-oil or no-oil salad dressings use iota or kappa to help suspend herbs, etc., and to provide the mouth feel that is expected from a normal salad dressing. The low oil content of reduced-oil mayonnaise normally gives a thin product, rather like a hand lotion; additives are needed to thicken it and to stabilize the oil-in-water emulsion. A combination of carrageenan and xanthan gum is effective. Xanthan gum is made by a bacterial fermentation process; its development was pioneered in the early 1960s by the Kelco Company, then the largest producer of alginate; it is now an accepted and widely used food additive. The interaction of carrageenan and protein can be used in the clarification of beer, with the complex formed precipitating from the wort. More water-based applications of carrageenan are given in the references below.

7.3.3 Meat products

In preparing hams, addition of carrageenan to the brine solution used in pumping improves the product because the carrageenan binds free water and interacts with the protein so that the soluble protein is retained. For successful penetration, the brine solution must have a low viscosity, but dissolved carrageenan would increase the viscosity. The carrageenan is therefore dispersed in the water after the brine salts are added; the carrageenan does not dissolve because of the high salt concentration, but as the ham cooks it does dissolve and is then effective.

There is a growing consumer demand for pre-cooked poultry products such as chicken and turkey pieces. Poultry processors were concerned about the loss of water during cooking (this lowered their yield per unit weight of product) and the loss in texture and eating quality that resulted. By injecting a brine containing salt, phosphate and carrageenan into the muscle of the meat, these problems are overcome. As the meat cooks, the carrageenan binds water within the poultry muscle and improves texture and tenderness. The processors are pleased because they now have a higher yield; in fact they find that he can even add some extra water to the poultry and it will be retained. The consumer receives a better product. The carrageenan producer is pleased because about 0.5 percent carrageenan is added, much more than the 0.05–0.1 percent used in dairy products. The future looks bright for this kind of application in meat products.

Hydrocolloids are being tried as fat replacements in low-fat products, with varying degrees of success. When fat or salt are reduced, meat and poultry can suffer loss of tenderness, juiciness and flavour. Low-fat products formulated with phosphates and carrageenan can have the juiciness and tenderness restored. Kappa carrageenan has been used with some success in replacing half the normal fat in frankfurters. Reduction of fat in ground meat products like hamburgers results in a different mouth feel and dry taste, which consumers do not always accept. Iota can be mixed with fresh ground beef and when cooked it provides fat-like characteristics and moisture retention that make the product more acceptable. This was the basis for McDonald's "MacLean" hamburger.

7.3.4 Pet food

This is the largest application for SRC, known as seaweed flour (see Section 7.1.2), using about 5 500 tonnes annually. Refined carrageenan could also be used, but its cost is too high and seaweed flour is about one-quarter of its price. Seaweed flour becomes an even better proposition because when combined with locust bean gum, less carrageenan is required, but this combination still gives an excellent product and it is very affordable. The meat used in canned pet foods is usually waste cuts from the abattoir. It is chopped into chunks or smaller pieces, mixed with water, flavours, seaweed flour (kappa carrageenan) and locust bean gum, canned and cooked. The two hydrocolloids help to bind the meat together and, depending on the concentrations used, either provide a thickened gravy around the meat pieces or a flavoured jelly, either of which enhances the appearance of the product as it is removed from the can. Konjac (or konjaku) gum, made from the konjac tuber or elephant yam (*Amorphophallus konjac*), can be used in place of locust bean gum. Konjac gels are clearer than locust bean gels and can help with costs when the price of locust bean gum rises, as it does occasionally.

7.3.5 Air freshener gels

When you need to improve the odours in your room, air freshener gels are one of the products available at supermarkets. They are made from kappa carrageenan, a potassium salt, water and perfume. When mixed, the perfumed gel forms and it is moulded to a shape to fit the holder. When purchased, the holder is sealed; to use, the holder is opened slightly and the moisture plus perfume are gradually released from the gel. Eventually the gel dries out leaving a small residue in the holder, which is then discarded. About 200 tonne/year of seaweed flour grade of carrageenan is the estimated consumption for this application.

7.3.6 Toothpaste

The essential ingredients in toothpaste are chalk or a similar mild abrasive, detergent, flavour, water and a thickening agent that will provide enough body to the paste to ensure that the abrasive is kept in suspension and that there is no separation of water. A thixotropic thickener is preferable, i.e. that has gel-like properties when allowed to stand but that will flow when pressure is applied to it. Iota carrageenan, at about 1 percent, is one of the most useful thickening agents, it meets the above criteria and gives a paste that is easily rinsed from the toothbrush. When the size of the toothpaste market is considered, even at 1 percent concentration this represents a large market for iota.

7.3.7 Immobilized biocatalysts

This application was discussed for alginates in Section 5.3.3. Carrageenan gels are another medium for immobilizing enzymes or whole cells. Kappa carrageenan gives the strongest gels and beads made from this show sufficient mechanical strength for packing in columns, and yet they are permeable to most substances.

7.3.8 For further details

More information about the properties and applications of carrageenans can be found in the following references, the first two of which are probably the most useful: Stanley (1990), Therkelsen (1993), Nussinovitch (1997), Stanley (1987).

For quick reference to a list of uses and the concentrations of carrageenan required, see Tables 3.4 and 3.5 in Thomas (1997).

7.3.9 Refined grade vs natural grade

Natural grade carrageenan is cheaper to make and requires a smaller capital outlay, therefore its price is lower than the refined or filtered grade. Natural grade is now approved for human use in most applications and jurisdictions. For a very useful and interesting discussion of the pros and cons of refined versus natural grades in regard to their purity, composition, and comparative performance in various applications, see Bixler (1996).

7.4 MARKETS AND MARKETING OF CARRAGEENAN

A summary of carrageenan markets is shown in Table 9. The total market has a value of about US$ 300 million. The marketing of carrageenan poses similar problems to those previously described in Section 5.4 for alginate. The original companies invested heavily in processing equipment and provided strong research and development facilities to assist customers and promote sales. These companies are now part of large multinationals and have a strong commitment to selling the refined carrageenan that they have always produced, and they operate at about 80–85 percent capacity. With the introduction of the simpler processing required for seaweed flour, many small companies entered that market, which required very little R&D because sales were mainly to pet food producers who knew exactly what they wanted and how to use it. Some of these companies then expanded their operations to produce the PES/PNG grade for human consumption. They make a few basic kappa and iota carrageenans for use in meat products, and to a lesser degree in dairy products. However, they lack the technical marketing skills to sell their products against the larger multinationals. These smaller companies are mainly in the Philippines and Indonesia, and operate at probably about 50 percent capacity and some are possibly struggling to survive. Despite this, new production facilities continue to be built in China and eastern Africa.

TABLE 9

Carrageenan markets (2001)

Application	tonnes	%
Dairy	11 000	33
Meat and poultry	5 000	15
Water gels	5000	15
PES food grade	8 000	25
Toothpaste	2 000	6
Other	2 000	6
Total	33 000	100

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

While there are difficulties in production of carrageenan, marketing can be even more difficult without adequate technical expertise to assist customers in the use of the product. Producers of refined carrageenan are not especially interested in selling the less expensive PES grade if such sales are going to replace sales of their refined grade. So there are opportunities for PES producers to penetrate the human food market with their less expensive product, if they are willing to invest in the technical expertise needed to service those sales. This has already occurred in the United States of America, where about 20 percent of the market is now PES grade. There appear to be similar opportunities awaiting PES producers in European markets that are still predominantly users of the refined grade (H.R. "Pete" Bixler, 2002, *pers. comm.*).

7.5 FUTURE PROSPECTS

In developed markets, such as the United States of America, Europe and Japan, all known applications are almost fully exploited. There could be some expansion by replacement of some of the gelatin market because of health concerns about bovine spongiform encephalopathy, but also due to a growing vegetarian population. Elderly people tend to use more processed foods in their diets and as this population increases so too will carrageenan consumption. Taking these factors into account, a 2–4 percent growth per annum can be expected in developed countries, and there the market splits about 50:50 between dairy and meat applications.

In areas such as Central and South America, Eastern Europe and Southeast Asia, growth will be stronger. Here the per capita consumption of carrageenan should increase by 50 percent over the next five years, due to market penetration alone. Allowing for population growth and assuming a moderate economic growth, an expansion of carrageenan consumption by 5–7 percent per annum is likely. At present the market is split into approximately 20 percent dairy and 80 percent meat applications, but this is likely to change with a gradual increase in the dairy foods market (H.R. "Pete" Bixler, 2002, *pers. comm.*).

For further details, see Bixler (1996), who discusses recent developments in the manufacturing and marketing of carrageenan and is excellent reading for anyone interested in obtaining an overall view of the carrageenan industry.