Carrageenan supply chains in Indonesia

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Abstract. Increasing global demand and new product development of carrageenan will increase in the future. Therefore, it will affect to carrageenan supply chains, especially in Indonesia. The purposes of this study are to analyse the members and the flow of material and energy of carrageenan supply chains. Primary and secondary data were collected through field survey, in-depth interviews, and documentary analysis. Flow of material and energy was modelled by the software Umberto NXT Universal 7.0. The primary actors of a carrageenan supply chain are seaweed suppliers, farmers, local traders, large traders or exporters, and carrageenan processors. Seaweed suppliers, farmers, local traders, and large traders/exporters exist in Sulawesi Island. Most of the carrageenan companies are national base existing in Java Island. About 75% of semi-raw dried seaweed containing carrageenan is exported. The material and energy for producing refined carrageenan are larger than semi refined carrageenan.

Keywords: flow material and energy; refined carrageenan; semi-refined carrageenan; supply chain.

1. Introduction
Carrageenan is one of the potential products of seaweeds increasing in the future. Carrageenan is used as an emulsifier, stabilizer, thickener, and gelling agent in food and non-food industries: consumer goods, industrial products, and biotechnology fields. In food utilizations, carrageenan can be used in human food, especially in dairy products, such as ice cream, chocolate milk, evaporated milk, milk puddings, processed cheese, water dessert gels, low-calorie jellies, and baby foods; as well as pet food. Consumer good uses of carrageenan include binders for toothpaste, thickeners for shampoos and cleansers, substances in skin cream and lotions, and air fresheners. Carrageenan can be found in industrial products such as for abrasives, pigments, pharmaceutical products, textiles, and agricultural agent solutions. In biotechnology application, carrageenan is utilized as an immobilize biocatalyst [1-3].

The carrageenan products are Alkali-Treated Cottonii (ATC), Semi-Refined Carrageenan (SRC), and Refined Carrageenan (RC). ATC produce in the forms chips, or simply called cottonii chips. SRC produce in the forms chips, or simply called cottonii chips. SRC is dried alkali-treated cottonii chips which can be milled at a various particle sizes such as 40-60 mm due to the customer requirements. RC is produced by using the alcohol precipitation or gel pressing method. SRC and RC are sold in powder form in either a white or beige colour. SRC is widely used in the dairy and meat industries where clarity is not a requirement. RC and SRC are listed in ANNEX 1.
of the European Parliament and Council Directive 95/2/EC on Food Additives. RC and SRC are separately labelled in the European Union. RC is assigned as E407 and SRC as E407a. However, according to the FDA, there is no distinction between RC and SRC labelling; thus, both are labelled as ‘carrageenan’ on food products in the US.

The significance raw materials of carrageenan are red seaweeds which can be widely found in Indonesia. The total volume of production of seaweed during the 2012–2016 period has a positive trend by 11.8% on average [4]. In 2017, the national seaweed production was 10.8 million tons. The most important types of red seaweed are *Kappaphycus alvarezii* or *Eucheuma cottonii* (cottonii), *Eucheuma dentilacum* (spinosum), and *Gracilaria*. Cottonii and Spinosum are used for the carrageenan industry, whereas *Gracilaria* is the raw materials for the agar industry [3, 5]. The largest seaweed farming areas, especially for red types, can be widely found in the eastern part of Indonesia: The Island of Sulawesi, Moluccas, Bali, and Nusa Tenggara Island.

From demand aspect, there is an increasing demand from global market. Export volume and value of Indonesian seaweed (HS 121220) tend to increase in the future. From 2012 to 2016, the export volume increasing by 2.45% and the export value growing by 2.14%. The average of export volume was 186,728,22 tons and the average of export value was USD 161,422,512 from this period [6]. This condition will influence to carrageenan supply chains in Indonesia.

Supply chain management (SCM) concerns with integration of network organizations consisting of suppliers, manufactures, logistic providers, wholesalers/distributors, and retailers. The SCM aims are collaborating and managing the flow of products, services, finance, and information from suppliers to customers to achieve customer satisfaction, profitability, added value, and to create both efficiency and effectiveness. In the long term, the benefit of SCM is to achieve a competitive advantage within a system [7-11]. An important aspect in SCM is identifying supply chain members covering primary and supporting members. The primary members of a supply chain are all companies that conduct operational and/or managerial activities that are directly related to producing a specific product for a certain customer or market. The supporting members are companies that support resources, knowledge, utilities or assets for the primary members of the supply chain; they are not directly involved in the main production process of transforming raw materials into a product [7].

It is important to analyse carrageenan supply chains in Indonesia. The previous authors presented the seaweed supply chains in a specific area, such as in Gorontalo Province [12] and East Java Province [13]. The purposes of this paper are to analyse the members of carrageenan supply chains and to assess the flows of material and energy from seaweed farmers to carrageenan manufacturers. Our quantitative approach used the Umberto software. In this paper, we focus on semi-refined carrageenan and refined carrageenan supply chains.

2. Method

The data consist of primary and secondary data. The primary data were collected from field survey and in-depth interviews. The first survey collected general information of seaweed farming and seaweed industries from the Ministry of Marine Affairs and Fisheries Republic of Indonesia, the Center for Coastal and Marine Resource Studies- IPB University, and the Indonesian Seaweed Association. Afterwards, survey was conducted in the main regions where the largest region of seaweed farming and seaweed manufacturers are existed. The survey location covers nine cities which are spread in five provinces: Makassar and Maros (Province of South Sulawesi); Surabaya, Pasuruan, and Sidoarjo (Province of East Java), Bogor and Bekasi (Province of West Java), Cilegon (Province of Banten), and Mataram (Province of West Nusa Tenggara). In-depth interviews are used to gather the information for carrageenan supply chains covering their member and activities, as well as flow material and energy within the supply chain. Questionnaire were guided for in-depth interviews to the farmers, local collectors, large traders, and carrageenan companies.

The secondary data were gathered from the documents of the Ministry of Marine Affairs and Fisheries, the Ministry of Industry, and the Indonesian Seaweed Association, as well as through desk research. The flow material and energy of seaweed supply chain was described by the software Umberto NXT Universal 7.0 with a basis of 1 kg SRC, and RC. Umberto provides to visualize material and energy flow systems with a Graphical User Interface (GUI) and to calculate raw material
requirements and waste. Input and output data of SRC production were gathered from the companies. While the RC input and output were used from document surveys.

3. Result and Discussions

The flow of carrageenan supply chains both semi-refined carrageenan and refined carrageenan starting from the seaweed farmers to the large traders have relatively similar activities: sun drying, storage, packaging, and distribution. These activities are classified as the seaweed supply activities. For seaweed farmers, there are other activities covering cultivation and harvesting. Cultivation decisions are made based on the allocation or share of the sea area, time for sowing seedlings, and required resources for growing the plant. During harvesting, farmers should consider the right time for harvesting, transporting equipment and labour.

There are two groups of Indonesian seaweed farmers: independent and dependent farmers. Independent farmers can sell Raw Dried Seaweed (RDS) to a local trader or other traders they may want to sell it. The farmers get price based on a local trader price. Dependent farmers, on the other hand, should sell their seaweed to a specific local trader or a cooperative. The farmers and a local trader have made an informal agreement, usually based on providing financial assistance to the farmers.

A local collector purchases semi raw dried seaweed with high moisture content (> 35%) from farmers. Therefore, the seaweed is dried in three to four days under the sun to meet large traders or exporters requirement for an average of 32-35% water content for *E. cottonii*. There is also the occasional problem of increased weight caused by excess salt in the seaweed bale. These are the primary reasons why local collectors buy dried seaweed from farmers at a lower price. Furthermore, local traders have price authority, called a price-taker, when buying raw dried seaweed from farmers.

Local collectors, or middlemen, are mostly found in villages, districts and sub-districts nearby seaweed farmers. Local collectors can be representatives of carrageenan producers, independent institutions, or cooperatives formed by seaweed farmers. A local collector is usually a head of seaweed farmer groups and typically operates in groups of 50 to 100 farmers. The majority of local collectors from seaweed farmer groups can be found in Bali and South Sulawesi. A local trader sell and deliver the raw dried seaweed to large traders or exporters after large quantities of seaweed are collected from farmers.

Large traders clean, dry, and transport raw dried seaweed directly to carrageenan producers in Indonesia and abroad. Large traders/exporters distribute 25% raw dried seaweed of *E. cottonii* for carrageenan manufacturing in Indonesia and 75% for export, for example to China and Europe. After collection, the seaweed is dried for 24 hours to reach about 30-32% water content for *E. cottonii*, with less than 5% foreign matter or impurities. The drying area is 550 m$^2$ with an approximate capacity of 5 ton. The weight ratio of wet seaweed of *E. cottonii* and its raw dried seaweed ranges between 6:1 and 8:1 on average.

Large traders and/or exporters are located in the capital of the province, or sub-province, where they have a large warehouse to store the dried seaweed. They usually operate with 3 to 10 people and have 20 members from local trader groups. Most large traders act as exporters and are spread out across Surabaya (East Java) and Makassar (South Sulawesi). Semi raw dried seaweed are exported (75%) mostly to China.

Most of carrageenan manufacturers in Indonesia are national companies, and some are multi-national companies. More than 80% of the companies are located in Java Island which spread out in West Java and East Java. While traditional food companies widely operate in Bali and West Nusa Tenggara. They generally produce only one or two products such as semi-refined carrageenan and alkali-treated *cottonii*. However, it is also possible for them to produce many other products such as Java Biocolloid produces agar, carrageenan, and blended stabilizer products. Flow of semi-refined carrageenan (SRC), and refined carrageenan (RC) will be explained in the next section.

4. Semi-Refined Carrageenan Manufacturers

A semi-refined carrageenan (SRC) supply chain is described in Figure 1.
The primary goal of semi-refined carrageenan (SRC) production is to increase the gel properties in seaweed. The production of SRC consist of pre-treatment, alkali treatment, neutralization, chopping, drying, and milling. Pre-treatment is conducted to remove foreign matters from the dried seaweed. The process begins with the selection and washing of raw dried seaweed. It is important that the foreign matter is removed and the product is sufficiently washed before the extraction process because it will influence the quality of the gel strength.

It is preferable to chop the raw dried seaweed into lengths of approximately 5-8 inches before it is treated with the alkali solution, a process which helps to increase the seaweed’s surface area. After the chips are milled, they are dried under the sun or with a drying machine. Machine drying is mostly used to avoid microbial contamination, especially for food grade purposes.

Afterwards, the cleaned and sorted raw dried seaweed is extracted in hot alkali solution using potassium hydroxide for *E. cottonii* for two hours to reach 12% potassium hydroxide or three hours for 8% potassium hydroxide at approximately 80-85 °C while stirring occasionally. The potassium hydroxide solution has a pH in a range of 12-14. The optimum condition of the alkali treatment is to use potassium hydroxide at a pH level of 13 for 1 hour at 80 °C [14]. If the temperature is below 80 °C, raw dried seaweed cannot dissolve and kappa conversion does not happen. The alkali solution then helps with the swelling and maceration of the seaweed. The hydroxide aids in reducing the number of sulphate in the carrageenan and generates 3, 6-andhydro-D-Galactose, therefore increasing the gel strength of the carrageenan [3, 15, 16]

Next, the seaweed is neutralized by soaking in fresh water to extract the residual alkali [15]. In the following stage, the neutralized seaweed is chopped to a size of 2-4 cm. The seaweed is chopped and milled to improve mixing and the overall gel quality for end-products. Afterwards, the chopped seaweed is dried under the sun for one to two days: It is also possible to use a drying machine at 60-70 °C for about six hours to achieve the standard moisture content of 14% of SRC. Machine drying is mostly used to avoid microbial contamination, especially for food grade purposes. There are three optimal conditions for drying: drying at 70 °C for 5 hours, 60 °C for 8 hours, or 50 °C for 24 hours [14]. Finally, SRC is packaged and sealed using 25 kg of weight low-density polyethylene film materials. The final product can be stored for at least two years after the production date. Table 1 shows the input for producing 1 kg semi-refined carrageenan and its output.

The SRC production process takes roughly four hours with an average production of 13.3 tons. A company receives an average of 60 tons of raw dried seaweed per delivery from large traders. Chemical materials used in the process, such as potassium hydroxide, are imported from Korea or Taiwan at an average of 20 tons for each delivery with a lead time of 30 days. Other supporting materials, such as packaging materials, are bought from the shops located in larger cities of the province such as Makassar, Jakarta, and Surabaya. The companies frequently ship SRC to China,
South Korea, Europe, and the US, delivering an average of 20 tons each time, with a lead time of 2 to 7 days from order to delivery.

**Table 1.** Input and output of a semi-refined carrageenan supply chain.

| Input/Output | Material                  | Quantity | Unit | Process                                                                 |
|--------------|---------------------------|----------|------|--------------------------------------------------------------------------|
| Input        | Diesel                    | 0.35     | Kg   | Alkali treatment                                                         |
|              | Electricity, medium voltage| 16.20    | MJ   | Multiple processes: drying, milling, alkalai treatment, packaging, and chopping |
|              |                           | 15.61    | MJ   | Multiple processes: alkali treatment, packaging, chopping, and milling   |
|              | Potassium hydroxide       | 0.20     | Kg   | Alkali treatment                                                         |
|              | Water, well, in ground [natural resource/in water] | 0.05     | m³   | Multiple processes: neutralization, alkali treatment, and pre-treatment  |
|              | Wet seaweed of *E.cottonii*| 33.13    | Kg   | Seaweed harvesting                                                       |
| Output       | Losses of raw dried seaweed | 0.11     | Kg   | Pre-treatment                                                           |
|              | Losses of SRC             | 0.02     | Kg   | Milling                                                                  |
|              | Losses wet seaweed of *E.cottonii* | 1.66     | Kg   | Seaweed harvesting                                                       |
|              | Packaged semi-refined carrageenan | 1.00     | Kg   | Packaging                                                                |
|              | Wastewater, average       | 0.05     | m³   | Multiple processes: neutralization, alkali treatment, and pre-treatment  |

*the SRC powder is dried using oven drying.

**5. Refined Carrageenan Manufacturers**

A refined carrageenan supply chain is shown in Figure 2.

![Figure 2. A refined carrageenan supply chain.](image)

There are two methods for extracting and refining carrageenan: the alcohol precipitation method and the gel press method, both of which are intended to extract carrageenan and transform it into a solid product. The alcohol precipitation method can be used for all types of carrageenan production, while the gel press method can only produce kappa carrageenan. The gel press method originated in agar processing and has been widely used in the processing in the Asian jellies [17].

Most carrageenan companies in Indonesia use the pressing method due to its lower production costs. Usage of the alcohol precipitation method has been decreasing over recent years due to high...
production costs. With this method, additional costs are necessary for the installation of a non-flammable tool, alcohol purifying distillation equipment, large quantities of alcohol and the cost of alcohol removal [16-18].

In this paper, the gel press method is chosen for quantifying the supply chain of refined carrageenan. The first step of the gel press method is similar to SRC production. To begin with, the seaweed is washed in running water to remove sand, salts and other foreign matter. Then, the washed seaweed is heated with water containing alkaline reagent such as sodium hydroxide or potassium hydroxide. Alkali is used to reduce sulphate from the molecules and increase the 3, 6-Anhydro-D-Glucose. After the alkali treatment, seaweed that does not dissolve is removed by a coarse filtration or centrifugation system, the solution is then filtered again in high temperatures. Following this step, the solution contains 1-2% carrageenan that is usually concentrated to 2-3% by vacuum distillation and ultrafiltration.

After the carrageenan solution is filtrated, it is streamed through fine holes into potassium chloride solution to form a gel. Water in the gel is removed through two methods: the freeze-thaw method and the gel press method. In the freeze-thaw method, the gel is collected and washed with more potassium chloride to remove excess water. The gel is then frozen and thawed to further assist in excess water removal.

The gel pressing method can be done by forcing water out of the gel with the use of pressure equipment. After it is squeezed for several hours, the sheets of gel are chopped and dried in a hot air dryer. The dried carrageenan is then milled to an appropriate size according to buyer specifications. Before the carrageenan powder is packaged and stored, it is blended with various materials to meet the varying requirements of buyers.

Table 2 describes input and output for 1 kg production of refined carrageenan.

| Input/Output | Material Description | Quantity | Unit | Process Details |
|--------------|----------------------|----------|------|-----------------|
| Input        | Electricity, medium voltage | 173.69 | MJ   | Multiple processes: extraction, packaging, gel pressing, freezing, fine filtration, precipitation, coarse filtration, agitation, drying, and milling |
|              | Filter aid           | 169.90   | Kg   | Coarse filtration |
|              | Potassium chloride, as K₂O | 1.33 | Kg | Precipitation |
|              | Potassium hydroxide | 0.28 | Kg | Extraction |
|              | Water, well, in ground [natural resource/in water] | 0.31 | m³ | Multiple processes: coarse filtration, extraction, pre-treatment, and precipitation |
|              | Wet seaweed of *E. cottonii* | 45.97 | Kg | Seaweed harvesting |
| Output       | Losses of raw dried seaweed | 0.15 | Kg | Pre-treatment |
|              | Losses of RC | 0.02 | Kg | Milling |
|              | Losses wet seaweed of *E. cottonii* | 2.30 | Kg | Seaweed harvesting |
|              | Packaged RC | 1.00 | Kg | Packaging |
|              | Residue | 5.66 | Kg | Coarse filtration |
|              | Residue 2 | 60.96 | Kg | Fine filtration |
|              | Wastewater, average | 0.31 | m³ | Multiple processes: pre-treatment, extraction, precipitation, coarse filtration |
6. Conclusions
There are the primary members of a carrageenan supply chain: seaweed farmers, local collectors, large traders/exporters, and carrageenan companies. Seaweed suppliers consisting of seaweed farmers, local collectors, and large traders/exporters have similar activities. The activities are sun drying, storage, packaging, and distribution. Producing 1 kg refined carrageenan requires the largest electricity (173.69 MJ) and water (0.31 m³). Wet seaweed is needed 33.13 kg for producing 1 kg semi-refined carrageenan. While, for refined carrageenan production (basis 1 kg) requires 45.97 kg wet seaweed. Potassium hydroxide for 1 kg refined carrageenan (0.20 kg) is higher than semi-refined carrageenan (0.20 kg). For the purpose of this paper, waste water is assumed to have the same value as the water requirements for all production systems.

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