

Seaweed processing industry supply chain model in Southeast Sulawesi

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Abstract. This study aims to analyze the procurement of raw seaweed materials from cultivating farmers for the ATC Chips processing industry at PT. INRI and design a supply chain model for the seaweed processing industry in Southeast Sulawesi. The study used a purposive sampling method with a Proportionate Stratified Random Sampling technique, involving 74 samples from three districts in Southeast Sulawesi: Bombana, Muna, and Wakatobi. The sample comprised large traders, village collectors, seaweed farmers, cooperatives, and the processing industry. Data was collected using primary and secondary sources. Data analysis included descriptive and quantitative methods, with the Economic Order Quantity (EOQ) method used to analyze raw material needs, alongside studies of product flow, financial flow, and information flow within the supply chain. The results show that the optimal raw material order quantity is 17,876.04 kg per order, with an order frequency of 60 times per year. The raw material supply chain flows from farmers through village collectors and large traders to the industry. The payment system is conducted via cash and bank transfer, with a 50% advance payment. [The study also reveals that cooperation between producers and retailers occurs through informal agreements. The industry's cooperation with other parties, namely retailers and/or producers in raw material procurement, is conducted through a contract system.

Key Words: ATC Chips, EOQ, raw material procurement, seaweed, supply chain.

Introduction. Seaweeds are marine plants belonging to the macroalgae group within the Thallophyta division. These plants characterized by the lack of clear differentiation between roots, stems, and leaves; the entire plant body is called a thallus (Tenriawaruwaty et al 2022). Furthermore, seaweed is a crucial aquaculture commodity for boosting production, regional economies, and the welfare of coastal communities. The development of the seaweed sector requires an integrated approach that combines human capacity building, research support, technological extension, and value chain diversification to ensure sustainable economic and social benefits for coastal communities. Such an approach can be implemented through vocational education institutions, including vocational high schools and community colleges, which can serve as strategic platforms for training, innovation, and community empowerment (Rimmer et al 2021).

Seaweed production in Southeast Sulawesi is currently dominated by *Eucheuma cottonii* and *Eucheuma spinosum*. These two seaweed types are the primary raw materials for various industries. Their carrageenan content ranges between 54 and 73% (Sufa & Syamsinar 2023). Specifically, *E. cottonii* seaweed has the potential to be processed into agar powder and Alkali Treated Cottonii (ATC) flour (Andriani 2006). Based on processing methods, ATC is divided into several types, including ATC Low Alkali, ATC Chips, and Seaweed Flour or Semi Refined Carrageenan (SCR) (Alviana 2015). The processing of *E. cottonii* into ATC involves an alkali treatment process that aims to improve the quality of carrageenan by altering the chemical structure of polysaccharides. Variations in the type and concentration of alkali significantly influence the quality of the final product, including gel strength, yield, and viscosity (Mustapha et al 2011).

In Southeast Sulawesi, the supply of raw seaweed for ATC processing faces shortages. This shortage is caused by seaweed quality not meeting industrial standards. Seaweed quality required for the ATC processing industry must be harvested after 45 days

and be free from marine impurities like sand and moss. In Southeast Sulawesi Province, seaweed harvest timing is often influenced by market demand. When market prices rise, farmers frequently harvest earlier than recommended. This occurs due to a lack of extension services and training provided to seaweed farmers by relevant authorities.

Ensuring raw material availability to meet domestic and global market demands requires collaboration among various stakeholders, particularly in seaweed marketing. These stakeholders include farmers as producers, intermediary traders or collectors, and processing industries that transform raw materials into semi-finished products. Herjanto (2007) stated that a supply chain is a series of interrelated activities and decisions designed to efficiently integrate suppliers, manufacturers, warehouses, transportation, retailers, and consumers. This enables the distribution of goods and services in the right quantities, at the right time, and to the right locations to minimize costs while meeting consumer needs. The supply chain approach focuses on cultivation, raw material processing, and product delivery to consumers through distribution systems. Consumer participation is vital in the supply chain, as they provide information about product requirements that producers must fulfil. With good information flow at each supply chain stage, the process of meeting consumer needs can be optimized (Chopra & Meindl 2016). Supply chain management refers to a managerial approach that integrates multiple activities associated with the flow of products, information, and financial resources from raw material suppliers to the final consumers. This approach highlights the importance of coordination and collaboration among supply chain participants to improve operational efficiency and generate added value for customers (Sabet et al 2017).

Given the rising global demand for raw seaweed, both dried and semi-processed, the Indonesian government developed the seaweed industry through Presidential Regulation Number 33 of 2019. This effort involves various stakeholders to boost Indonesian seaweed production. Based on the national seaweed industry development roadmap initiated by the government for 2018-2021, seaweed factories are spread across five provinces: North Kalimantan, Gorontalo, North Maluku, South Sulawesi, and Southeast Sulawesi (Ningsih 2020).

The government launched a program to develop nine seaweed factories in five provinces, including Southeast Sulawesi, which received three locations: Bomana Regency, Buton Regency, and Central Buton Regency. Of these, only the factory in Bomana Regency remains actively operational and is expected to enhance the welfare of seaweed farmers in Southeast Sulawesi. This is significant as almost all regencies and cities in the region, except East Kolaka Regency, Konawe Regency, and Kendari City, are seaweed-producing areas.

The currently operational seaweed industry in Southeast Sulawesi is the factory in Bombana Regency, managed by PT. Inti Nusa Raya Indonesia (PT. INRI), one of Indonesia's largest seaweed companies. This company produces processed seaweed in the form of Alkali Treated Cottonii Chips (ATC Chips). The factory's presence is expected to support and benefit seaweed farmers, especially in Bombana Regency. Based on this, the research identified problems concerning irregular raw material procurement and poorly coordinated raw material supply chains for the seaweed processing industry.

Material and Method

Description of the study sites. This research was conducted from May to June 2021 in three districts in Southeast Sulawesi Province with abundant and consistent raw seaweed supplies: Bombana (Poleang), Muna (Lohia, Bhone Bhalano, Ghai), and Wakatobi. The study area was selected due to its role as the principal supply hub for PT. Inti Nusa Raya Indonesia (PT. INRI) and its status as the largest seaweed-producing region in Southeast Sulawesi.

Data collection. Samples were taken using a representative method with Proportionate Stratified Random Sampling technique, ensuring each sample accurately reflects the overall population conditions. We conducted interview with 74 respondent from various seaweed supply chain actors, i.e. seaweed farmers (65 respondents), village collectors (3

respondents), large collectors (4 respondents), and seaweed processing industry managers (2 respondents).

The data used in this study were obtained from both primary and secondary sources. Primary data were collected through field observations, surveys, and in-depth interviews with key actors involved in the seaweed supply chain. Secondary data were obtained from relevant scientific journals, textbooks, conference proceedings, previous research studies, and official publications from government institutions, including the Ministry of Maritime Affairs and Fisheries, the Agency for the Assessment and Application of Technology (BPPT), and the Central Statistics Agency (BPS). To examine the supply chain model of the seaweed processing industry, this study analyzes the raw material procurement system and the overall supply chain structure of the seaweed industry at PT Inti Nusa Raya Indonesia.

Data analysis. Analysis of raw material procurement for seaweed production was conducted descriptively using the Economic Order Quantity (EOQ) method. This method is an inventory control model used to determine the optimal quantity of raw material orders to minimize total inventory costs, including ordering and holding costs. This model remains widely utilized in contemporary operations management studies because it enhances the efficiency of inventory management while ensuring the continuous availability of raw materials required for production activities (Alnahhal et al 2024). This method aims to determine the optimal quantity of raw material per order to minimize (Nugraha et al 2024). The EOQ calculation is formulated as follows:

$$EOQ = \sqrt{\frac{2 \cdot R \cdot S}{P \cdot I}}$$

where: R = total material requirement (units/month);
S = ordering cost (IDR/order);
I = holding cost (carrying cost) (% of item value);
P = raw material price (IDR/kg).

Analysis of the seaweed raw material supply chain from farmers to the processing industry in Southeast Sulawesi was conducted by examining three key dimensions: product flow, financial flow, and information flow. Product flow analysis was employed to evaluate marketing margins and supply chain efficiency. Meanwhile, financial flow and information flow were analyzed using a descriptive approach to assess the mechanisms of financial transactions and information exchange among supply chain actors. This integrated analysis provides a comprehensive understanding of the operational and coordination processes within the seaweed supply chain.

Results and Discussion. The findings of this study elucidate the mechanisms of seaweed raw material procurement, production practices at the farm level, industrial demand for raw materials, and the structure of the seaweed raw material supply chain.

Raw seaweed procurement. Raw material procurement is a key element supporting smooth production processes. If raw material availability is insufficient, a company's production process can be disrupted. The industry's need for raw materials is paramount, as raw materials are the main component in the production process. The availability of raw material supply is a key factor in maintaining production continuity and ensuring the stability of the industrial supply chains (Ivanov 2021). Therefore, procurement plays a vital role in the processing industry. This process is also closely related to company operational costs. The larger the quantity of raw materials procured, the higher the incurred costs. These costs include not only warehouse storage but also expenses arising from ordering through to usage in production and subsequent storage as finished goods (Ristono 2009).

Seaweed production at farmer level. In 2019, seaweed production in Southeast Sulawesi Province declined, with total production reaching 346,886 tons (BPS 2021). This decline was caused by unstable seaweed price fluctuations across producing regions.

Production within the province is also uneven. For instance, Bombana Regency recorded production of 23,576 tons, Muna Regency reached 136,439 tons, and Wakatobi Regency produced 22,453 tons in the same year (BPS 2021). Farmers in these regions typically produce seaweed four times a year. Respondent data shows significant differences in production volume between districts. Respondent farmer production is shown in Table 1.

Table 1

Seaweed production in a year

No	District	Avg production (kg/production cycle)	Respondent (individual/group)	Total production (kg year ⁻¹)
1	Bombana	2,000	5	40,000
2	Wakatobi	135	35	18,880
3	Muna	300	29	34,800
Total				93,680

The production data from respondent farmers indicate that the total seaweed output reaches 93,680 kg per year. However, this amount is insufficient to support the production of ATC chips, while the industry requires a raw material supply of up to 1,080 tons of seaweed annually. As a result, industrial production runs below machine capacity. However, considering Southeast Sulawesi's total seaweed production of 346,886 tons per year, the ATC Chips raw material requirement could be met. Therefore, the industry needs to develop or expand its raw material supply sources beyond existing ones. Insufficient seaweed production meeting ATC Chips standards will hinder the production process, leading to reduced output volume. Furthermore, using substandard seaweed will result in lower quality ATC Chips.

Industry raw material requirement. PT. Inti Nusa Raya Indonesia operates in seaweed processing. The company significantly contributes to the economy of Southeast Sulawesi, especially coastal areas, by supporting seaweed farmers living along the coast. As one of Indonesia's companies, PT. Inti Nusa Raya Indonesia processes dried seaweed into ATC Chips. It has a production capacity of up to 10 tons per day, but due to facility limitations and raw material supply constraints, average daily production only reaches 3 tons.

With an average raw material usage of 3 tons per production run, the estimated monthly requirement is about 90 tons, meaning the annual requirement for ATC Chips production is about 1,080,000 kg or 1,080 tons. To meet this, the industry incurs ordering costs, including communication costs (phone credit) to contact suppliers (large traders or farmers directly) and fuel costs for collection at ports or within Bombana Regency. The ordering cost consists of IDR 200,000 for communication and IDR 251,500 for fuel. The current raw material price is IDR 17,000 per kg, with a holding cost (carrying cost) of 10%. The most economical raw material requirement for ATC Chips at PT. Inti Nusa Raya Indonesia is shown in Table 2.

Table 2

Most economical raw seaweed requirement for ATC Chips at PT. Inti Nusa Raya Indonesia

No	Description	Unit	Value
1.	Most economical order quantity (EOQ)		
	Raw material requirement	kg	1,080,000
	Marketing cost	Rp	251,500
	Price	Rp kg ⁻¹	17,000
	Storage	%	10
	EOQ	kg	17,876.04
2.	Annual order frequency		
	Raw material requirement	kg	1,080,000
	EOQ	kg	17,876.04
	Load time	Times year ⁻¹	60

3.	Re-order point (ROP)		
	Load time	Times year ⁻¹	60
	EOQ	kg	12,640.27
	Number of days	Days year ⁻¹	360
	Ordering time	Days	6
	ROP	kg	3,000

Source: Processed primary data, 2021.

Based on Table 2, the annual raw material requirement is 1,080,000 kg (1,080 tons), with an ordering cost of IDR 251,500. Therefore, the most economical order quantity per purchase is approximately 17,876.04 kg (17.88 tons). Consequently, orders should be placed 60 times per year, with a 6-day interval between orders. Under these conditions, the remaining raw material inventory when reordering is estimated at 3,000 kg (3 tons). Insufficient daily production capacity due to a lack of quality raw materials meeting ATC Chips processing standards will result in delays in product distribution, hindering the ability to meet both national and international market demand.

Raw material supply chain. The seaweed supply chain involving PT. INRI includes several actors performing activities according to their roles. According to Chopra & Meindl (2007), a supply chain is dynamic but involves three constant main flows: information, product, and money. They also state that the primary goal of any supply chain is to satisfy consumer needs while generating profit. Meanwhile, Li (2007) explains that the supply chain focuses on all activities aimed at meeting consumer needs, encompassing the flow and transformation of goods from raw materials to the end consumer, accompanied by information and financial flows. The raw seaweed supply chain flow at PT. INRI is illustrated in Figure 1.

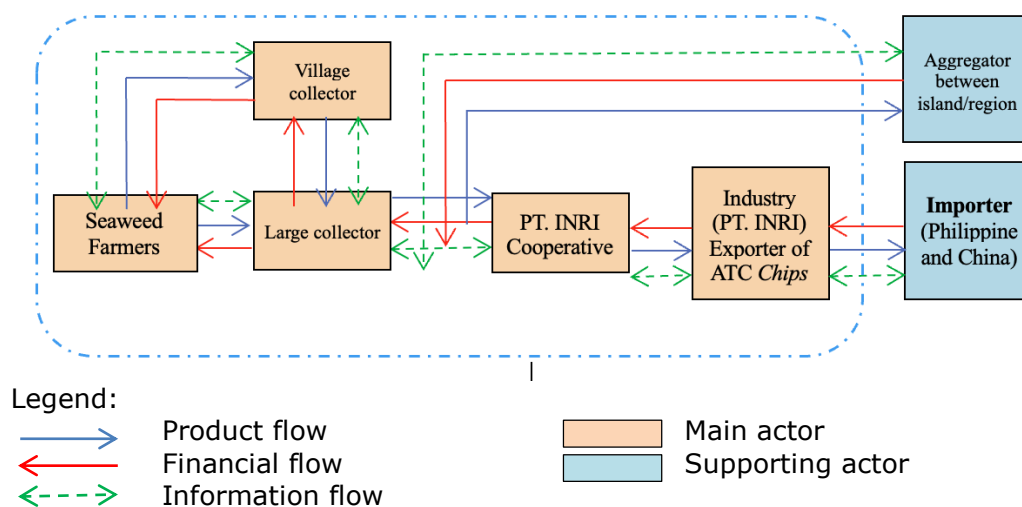


Figure 1. Raw seaweed supply chain flow at PT. INRI.

Product flow. Product flow in a supply chain refers to the movement of goods from raw material suppliers until the products reach the final consumers. In a supply chain system, product flow move from upstream to downstream through several stages, including production, distribution, and marketing (Mentzer et al 2001; Ivanov 2021). This process also involves the flow of raw materials from suppliers to consumers, including product returns, services, recycling, and disposal (Ibeng 2021). The raw seaweed supply flow starts with farmers as the primary producers, then moves through village collectors or large collectors, before finally reaching the ATC Chips processing industry via KLKM cooperatives.

Upstream supply chain. The upstream supply chain refers to the part of the supply chain that involves the relationship between a company and its raw material suppliers. At this stage, the main activities include raw material procurement, supplier management, and

supply coordination to support the smooth operation of the production process (Sabet et al 2017; Ivanov 2021). In 2019, Southeast Sulawesi's seaweed production reached 346,886 tons. Respondent production volumes from Bombana, Muna, and Wakatobi regencies totalled 93,680 kg, as detailed in Table 3.

Table 3

Seaweed production in 2019

No.	Regency	Production (kg)	Production by respondent (kg)	%
1	Bombana	23,576,000	40,000	0.17
2	Muna	136,439,000	34,800	0.03
3	Wakatobi	22,453,000	18,880	0.08
Amount		182,468,000	93,680	0.05

Source: Processed primary data, 2021.

Internal supply chain. Internal supply chain refers to the part of the supply chain system that occurs within an organization and involves coordination among various functions such as procurement, production, and inventory management. Effective internal integration enables companies to improve operational efficiency and enhance overall supply chain performance (Flynn et al 2010; Zhao et al 2011). Activities begin with raw materials entering KLKM cooperatives, which distribute all received materials to the industry. Materials received from cooperatives are sorted to remove impurities. Key steps include: production preparation, raw material cleaning, soaking, drying, and cutting. The ATC Chips production process is shown in Figure 2.

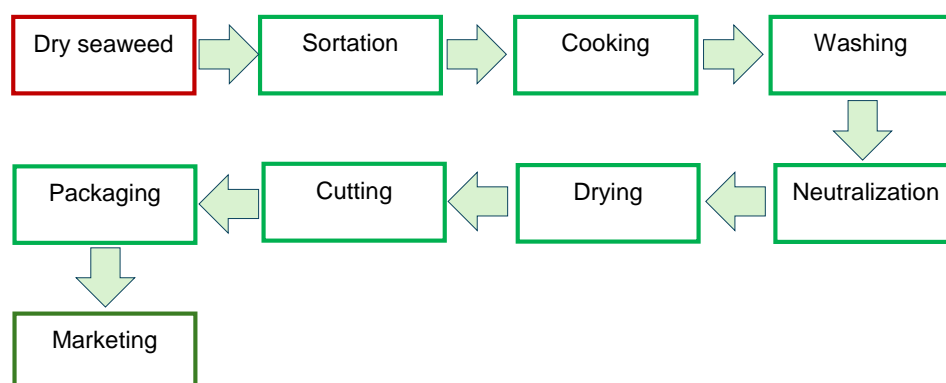


Figure 2. ATC Chips production process.

Downstream supply chain. The downstream supply chain refers to the part of the supply chain system associated with the distribution of products from manufacturers to distributors, retailers, and ultimately to final consumers. Effective integration between companies and customers within the downstream supply chain can improve distribution efficiency and enhance responsiveness to market demand (Huo 2012; Ivanov 2021). Indonesian carrageenan exports declined in the first quarter of 2019 and 2020, likely due to Covid-19 lockdowns. However, exports significantly increased in the second quarter, leading to an overall first-semester increase of 16.04% by volume and 8.61% by value.

Disruptions in product flow within the supply chain harm the entire system, from producers to consumers. Impacts include delays in fulfilling raw material or product demand, halted production processes, and increased operational costs.

Financial flow. Financial flow in the supply chain refers to the flow of payments and financial transactions that occur among supply chain members as compensation for the exchange of goods and services. Effective management of financial flows can enhance operational efficiency and strengthen relationships among suppliers, manufacturers, and customers within the supply chain network (Pfohl & Gomm 2009; Gelsomino et al 2016). Financial flow or money flow refers to the movement of funds starting from the consumer

(buyer) and flowing back through each link to the producer for production costs. The financial flow pattern moves from the industry (PT. INRI) to seaweed farmers. Payment is made by the industry via KLKM Cooperatives using two methods: cash and bank transfer. The financial flow from the industry stops at the cooperative, which then channels funds to large collectors. Large collectors, in turn, pass funds to village collectors, who finally pay the producers. Payments from village collectors go directly to producers.

Disruptions in financial flow cause insufficiently solid cooperation between marketing institutions. This results in delayed payments between supply chain actors, causing recipients difficulty financing operational activities. Furthermore, financial disparities arise, making small actors or producers economically dependent and vulnerable. Financial flow is the lifeblood of the supply chain. If disrupted, the entire system from upstream to downstream falters, ultimately reducing efficiency, productivity, and industrial competitiveness.

Information flow. Information flow in the supply chain refers to the exchange of data and communication among supply chain members such as suppliers, manufacturers, distributors, and customers. Accurate and timely information can enhance operational coordination, reduce demand uncertainty, and improve overall supply chain performance (Lee et al 1997; Zhou & Benton 2007). Information flow refers to the exchange occurring both upstream (from producer to consumer) and downstream (from consumer to producer). Information flows reciprocally between producers and consumers concerning raw seaweed, order quantities, selling prices, and required quality specifications. Information flow can be vertical or horizontal. The industry communicates price and demand information to the cooperative. The cooperative relays this information to large collectors. Large collectors then inform village collectors and farmers directly about seaweed prices.

Disruptions in information flow affect the efficiency, coordination, and responsiveness of the entire system. Consequences include mismatches between supply and demand, disrupted coordination between actors, increased operational costs, reduced responsiveness to market changes, diminished trust and collaboration, and lower production quality.

Conclusions. Based on the analysis we found that farmer-level seaweed production of 93,680 kg per year remains relatively low, while the annual raw material requirement reaches 1,080,000 kg (1,080 tons). The optimal order quantity is 17,876.04 kg, requiring 60 orders per year at 6-day intervals. Three key supply chain flows require management: i.e. a). Product flow: raw seaweed flows from farmers (cultivators) through village collectors and large collectors to the industry (end consumer). b). Financial flow: funds flow from the industry (consumer) through large collectors and village collectors to farmers (producers). Payment by the industry is via cash or bank transfer with a 50% advance payment. Large and village collectors pay farmers in cash; and c). Information flow: weaknesses exist in the raw material procurement contract system, primarily managed only at the cooperative level.

Conflict of interest. The authors declare that there is no conflict of interest.

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