Science and Technology Indonesia
e-ISSN:2580-4391 p-ISSN:2580-4405
Vol. 10, No. 4, October 2025

Review Paper

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Potential of Tropical Seaweed Carageenan in Applications of Soft Capsule as a Replacement for Gelatin: A Review

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Abstract
Carrageenan, a natural sulfated polysaccharide extracted from red seaweed, has attracted considerable attention in the development of drug delivery systems, particularly as a capsule-forming material. With its biodegradable, biocompatible properties and gel-forming ability, carrageenan holds significant potential as a plant-based alternative to animal-derived gelatin. This review aims to evaluate the potential of carrageenan, especially iota-carrageenan, in the production of soft capsules as a gelatin substitute, and to compare the characteristics of hard and soft carrageenan-based capsules. In addition, formulation challenges and structural modification strategies are discussed to improve the functional properties of carrageenan. Soft capsules are typically formulated using iota-carrageenan and plasticizers such as glycerol to achieve optimal flexibility, while hard capsules utilize kappa-carrageenan due to its stronger gel texture. Modifications such as depolymerization and blending with other polymers have been shown to enhance viscosity, elasticity, and disintegration time of carrageenan capsules. However, several limitations remain, including high viscosity and slower disintegration rates compared to gelatin-based capsules. Therefore, formulation optimization and improved extraction techniques are essential for advancing carrageenan capsules as competitive alternatives in pharmaceutical applications. Looking forward, future research should focus on optimizing low-cost and high-purity carrageenan extraction methods, engineering depolymerization processes, and modifying kappa-carrageenan to exhibit iota-like flexibility. These approaches are expected to improve the feasibility of using tropical seaweed-derived carrageenan as a sustainable and halal-compliant material for soft capsule shells.

Keywords
Carageenan, Red Seaweed, Seaweed, Soft Capsule Shell

Received: 15 December 2024, Accepted: 31 August 2025
https://doi.org/10.26554/sti.2025.10.4.1288-1300

1. INTRODUCTION

Algae are a diverse group of simple aquatic plants with a long evolutionary history, widely distributed in various marine habitats. One significant subgroup of algae is seaweeds (macroalgae), which are classified into red, brown, and green seaweeds based on their pigmentation. The cell walls of red seaweeds are predominantly composed of sulfated polysaccharides such as carrageenan and agar, which play vital roles in structural support, energy storage, and selective cation absorption (Pangestuti and Kim, 2014). Carrageenan is a major polysaccharide extracted primarily from *Kappaphycus alvarezii* and *Eucheuma denticulatum*, two red seaweed species widely cultivated in Southeast Asia, including Indonesia (Imeson, 2009).

Commercial carrageenan is typically classified into three main types based on its structure and gel-forming properties: kappa (κ), iota (ι), and lambda (λ). Kappa-carrageenan forms strong and brittle gels in the presence of potassium ions; iota-carrageenan forms soft, elastic, and transparent gels in the presence of calcium ions; and lambda-carrageenan does not form gels and is generally used as a thickening agent in liquid products (Pangestuti and Kim, 2014).

Soft capsules are among the most commonly used oral pharmaceutical dosage forms due to their ability to protect liquid active ingredients from oxidation while improving patient compliance. These capsules can mask unpleasant tastes and odors, provide airtight sealing, and rapidly disintegrate in the stomach upon administration (Gullapalli and Mazzitelli, 2017). Traditionally, soft capsules are made from gelatin derived from animal sources such as bovine or porcine collagen (Nafchi et al., 2014). However, gelatin poses several issues, including dietary and religious restrictions (e.g., for muslim, jewish, vegetarian, or vegan populations), as well as health concerns such as the risk of bovine spongiform encephalopathy

(BSE), thereby highlighting the need for plant-based and safer alternatives (Gullapalli and Mazzitelli, 2017).

Carrageenan has emerged as a leading candidate for replacing gelatin in capsule formulation in recent years. However, it is important to note that not all types of carrageenan are suitable for soft capsules. Although comparable to gelatin in gel strength, Kappa-carrageenan is more appropriate for hard capsule applications due to its brittle gel texture (Soraya et al., 2024). In contrast, iota-carrageenan is more suitable for soft capsule applications because of its ability to form flexible and elastic gels, which are essential for maintaining the mechanical integrity of soft capsules during processing, storage, and administration (Hilliou, 2021; Pangestuti and Kim, 2014).

Despite these advantages, using iota-carrageenan in soft capsule formulation still faces several technical challenges, including low solubility, high viscosity, and slower disintegration time compared to gelatin capsules (Fauzi et al., 2020). Additionally, the high molecular weight of carrageenan contributes to poor solubility and excessive gel strength. To overcome these limitations, strategies such as molecular depolymerization have been explored. For instance, Tecson et al. (2021) utilized ultrasonic-assisted depolymerization, which successfully reduced the molecular weight of kappa-carrageenan by 96.33%, thereby improving its potential for drug delivery systems.

This review aims to evaluate the potential of iota-carrageenan, derived from red seaweed, as a plant-based alternative to gelatin for soft capsule applications. It will examine the physicochemical characteristics, formulation challenges, and possible strategies to enhance its pharmaceutical performance, including structural modification and excipient combinations.

2. Characteristics of Tropical Seaweed

Several previous researchers have observed the chemical properties of seaweed in Indonesia. The chemical properties of seaweed can be seen in Table 1.

The chemical composition of seaweed varies significantly depending on species, habitat, harvest season, and initial processing methods. Table 1 presents the chemical profiles of several tropical seaweed species commonly found in Indonesian waters and neighboring regions. Key chemical parameters analyzed include moisture content, ash, protein, lipid, and crude fiber levels. For example, *Eucheuma cottonii*, a significant source of kappa-type carrageenan, contains 7.21% protein, 0.47% lipid, and 8.52% crude fiber. These values indicate a high fiber and low-fat content, favorable traits for carrageenan extraction. The quality of the seaweed, how it is processed, and the water's environmental conditions all impact the carrageenan quality (Hajar and Parden, 2023).

Other species, such as *Sargassum polycystum*, also show potential as raw materials, with ash contents ranging from 21.38% to 30.78%. High ash content may reflect significant mineral presence, but can also negatively affect the clarity and quality of the final carrageenan product if not correctly managed during processing. Ash content is an important factor in evaluating the nutritional value of seaweed. A high ash level makes seaweed less suitable for human consumption, reducing its effectiveness as a food source (Alghazeer et al., 2022). Meanwhile, species like *Caulerpa racemosa* and *Caulerpa mexicana* exhibit high protein levels (up to 20.79% in *C. cupressoides*), which may not be ideal for carrageenan extraction due to differences in polysaccharide structure, but may be better suited for functional food or dietary supplement applications.

These variations in chemical composition not only influence carrageenan content but also affect the extraction process, yield efficiency, and the physical and chemical quality of the resulting carrageenan. For instance, seaweeds with high moisture content are prone to faster degradation of bioactive compounds if not promptly dried. In contrast, high protein and lipid levels may contaminate the final product, requiring additional purification steps. Therefore, selecting the right seaweed species ensures quality and production efficiency.

Moreover, environmental factors such as salinity, temperature, and nutrient availability in seawater also influence the biosynthesis of bioactive compounds, including carrageenan. As such, cultivation and post-harvest practices play an important role in determining the quality of seaweed biomass.

A thorough understanding of the chemical characteristics of different seaweed species allows for optimizing appropriate extraction strategies, including the choice of method, processing conditions, and necessary pre-treatments. The following section will explore the various carrageenan extraction methods commonly used, and how these methods are adapted to different seaweed compositions.

3. Extraction Method of Carrageenan

Carrageenan can be extracted using various methods such as alkaline, enzymatic, or thermal extraction, each influencing its structural and functional properties. Different extraction techniques affect the yield. Extraction using hot alkaline solvents can reduce operational costs because it only requires simple equipment and lower energy consumption. However, this process takes longer due to the use of large amounts of solvent, which can cause waste of solution, increase the risk of microbiological contamination, and potentially damage high-value microalgae cell components due to alkali exposure (Firdayanti et al., 2023). According to Jiang et al. (2022), the resulting carrageenan results in low yields and the use of large amounts of chemicals and water, thus increasing wastewater treatment costs exponentially. Extraction methods can provide alternatives to minimize the use of chemicals with microwaves, ultrasonics, and enzymatic methods.

The microwave method has advantages including short curing time, suitability for heat-sensitive compounds, efficiency and uniformity in heating, and high extraction yields. However, this technology has several disadvantages, such as relatively high costs, the potential risk of explosion, especially in closed microwave systems, challenges in temperature control, and the possibility of microwave leakage, which needs to be managed properly to ensure safety and prevent health risks.

Table 1. Chemical Properties of Dried Tropical Seaweeds

Types of Seaweed	Location	Water (%)	Ash (%)	Protein (%)	Lipid (%)	Crude Fiber (%)	Sources
S. polycystum	Teluk Kemang	13.70	21.38	8.65	3.42	13.55	(Nazarudin et al., 2021)
Caulerpa cupressoides	Pacheco Beach	12.21	11.28	20.79	3.77	–	(Carneiro et al., 2014)
Caulerpa Mexicana	Pacheco Beach	10.70	7.79	18.06	1.52	–	(Carneiro et al., 2014)
Hypnea musciformis	Pacheco Beach	14.17	14.14	17.12	0.33	–	(Carneiro et al., 2014)
Solieria filiformis	Pacheco Beach	15.06	15.12	20.31	0.34	–	(Carneiro et al., 2014)
U. lactuca	Pameungpeuk Waters	16.90	11.20	13.60	0.19	–	(Rasyid, 2017)
Gracilaria seaweed	Karawang	11.34	5.54	9.43	0.26	–	(Purwaningsih et al., 2024)
Gracilaria seaweed	Lombok	9.51	6.58	10.73	0.62	–	(Purwaningsih et al., 2024)
Caulerpa racemosa	Tual, Southeast Maluku	14.66	38.41	7.60	0.71	–	(Pangestuti and Kim, 2014)
S. polycystum	Kelanit waters of Southeast Maluku	12.19	30.78	4.92	0.32	5.37	(Erbabley and Junianto, 2020)
S. filipendulla	Kelanit waters of Southeast Maluku	21.61	24.79	2.31	0.19	–	(Erbabley and Junianto, 2020)
P.minor	Kelanit waters of Southeast Maluku	22.31	30.53	4.78	0.52	3.81	(Erbabley and Junianto, 2020)
S.oligocystum	Kelanit waters of Southeast Maluku	9.40	13.08	5.64	0.46	6.49	(Erbabley and Junianto, 2020)
P.tetrastomatoca	Kelanit waters of Southeast Maluku	16.40	27.00	10.50	1.14	23.96	(Felix and Brindo, 2014)
E. spinosum	Nusa Penida	19.55	24.26	6.04	0.012	15.12	(Diharmi et al., 2019)
E. spinosum	Takalar	21.27	23.66	7.33	0.032	18.56	(Diharmi et al., 2019)
Eucheuma cottonii	Tanjung Medang	–	14.22	7.21	0.47	8.52	(Diharmi et al., 2020)
E. striatum	Mimapropa region	35.30	16.44	–	–	–	(Abel and Tolentino, 2024)
K. alvarezii	Mimapropa region	35.70	18.55	–	–	–	(Abel and Tolentino, 2024)
E. denticulatum	Mimapropa region	38.67	16.22	–	–	–	(Abel and Tolentino, 2024)

The ultrasonic extraction method has advantages including shorter drying time, more efficient use of solvents, improved gel texture quality, and better temperature control capabilities. However, this method also has several disadvantages, such as the need for additional stirring due to uneven mixing depending on the viscosity of the sample, and the risk of reducing the quality of the extract if the sonication process is carried out excessively (Firdayanti et al., 2023). Enzyme-assisted extraction can reduce the use of alkali and increase extraction yields. However, the carrageenan quality tends to be less than optimal because the enzyme is susceptible to inactivation, and its stability is difficult to maintain in a practical scale production process (Jiang et al., 2022).

The widely used extraction method is the alkali method be-

Table 2. Yield Results with Different Carrageenan Extraction Methods

Extraction Method	Yield (%)	Sources
Alkali ($Ca(OH)_2$)	24.7	(Jiang et al., 2022)
Alkali (NaOH)	21.0	(Jiang et al., 2022)
Microwave Assisted Extraction (MAE) - KOH 3% (1:10)	68.90	(Kasim et al., 2023)
MAE – KOH 3% (1:20)	25.61	(Kasim et al., 2023)
MAE - NaOH 0,1N (1:10)	52.87	(Kasim et al., 2023)
MAE - NaOH 0,1N (1:20)	37.32	(Kasim et al., 2023)
Microwave Assisted Extraction – KOH 3%	16.6	(Vazquez-Delfin et al., 2014)
Microwave Assisted Extraction - Aqueous	21.5	(Vazquez-Delfin et al., 2014)
Ultrasonic Assisted Extraction (UAE) – NaOH	33.73	(Mendes et al., 2024)
UAE – KOH	76.70	(Mendes et al., 2024)
NAC-Alkali	23.8	(Naseri et al., 2020)
Enzyme cellulase 0.2%, xylanase 0.2%, NAC-alkali	35.5	(Naseri et al., 2020)
Alcalase 0.2% + NAC-alkali	27.8	(Naseri et al., 2020)
Bead mill	67.86	(Firdayanti et al., 2023)

cause it can produce good quality carrageenan, lower costs, and the process is easier to implement on a large scale. However, current carrageenan production has complex manufacturing steps, such as the use of high concentrations of NaOH, and the amount of water used is large and requires significant investments in wastewater treatment. Several studies have innovated to overcome these problems. The carrageenan extraction process with $Ca(OH)_2$ for carrageenan extraction and CO_2 for neutralization as a substitute for the use of alkali (NaOH) has been carried out by Jiang et al. (2022) and Liu et al. (2022). The results showed that the quality of kappa carrageenan produced by $Ca(OH)_2$ extraction was superior to the extraction method with NaOH, such as increased gel strength, thermal stability, and decreased viscosity. In addition, a study with the same method on iota carrageenan showed results with a gel texture, such as better hardness and elasticity compared to the NaOH alkali extraction method, good thermal stability, and lower viscosity. In the study of Kasim et al. (2023), using KOH as an extraction solvent typically yields a higher amount of carrageenan than NaOH due to the higher molecular weight of potassium ions relative to sodium ions. Additionally, the efficiency of the extraction process is affected by both the volume-to-material ratio and the concentration of the alkaline solution used. The greater the volume and concentration of the alkaline solvent used, the greater the yield of carrageenan produced.

According to Jiang et al. (2022), this is due to the absence of preliminary alkali treatment. Without alkali, there is no conversion process of D-galactose-6-sulfate to 3,6-anhydrogalactose, which affects the formation of helical bonds and the stability of the molecular structure, so the resulting gel is not strong.

In another study by Firdayanti et al. (2023), a mechanical method, namely a bead mill, was used in carrageenan extraction. The results showed that the yield produced was higher, reaching 67.86% in a short time, namely ±50 minutes, compared to the conventional method using alkali KOH. However, the physicochemical characteristics, especially the gel strength produced, were lower than those of the conventional method with KOH solvent. Several other research results with different extraction methods on the yield of carrageenan can be seen in Table 2.

While numerous studies have explored diverse extraction methods for carrageenan, a critical gap remains in correlating extraction parameters with the functionality of carrageenan in pharmaceutical applications, particularly capsule shell formation. High yield does not always translate into better gel properties or biocompatibility. For example, the bead mill method provides exceptional yield but results in lower gel strength, limiting its use in soft capsule matrices that require mechanical integrity.

Additionally, the scalability of enzymatic and ultrasonic methods is yet to be validated in industrial settings, where cost, energy efficiency, and chemical use must be optimized. In this regard, green extraction technologies-such as enzymatic or microwave-assisted extraction using minimal solvents-need further exploration, especially within the framework of GMP (Good Manufacturing Practice) compliance.

Future studies should focus on developing a standardized extraction-performance evaluation framework that quantifies yield and assesses gel strength, viscosity, sulfate content, and biocompatibility in an integrated model. Such a framework would bridge the gap between academic innovation and real-world pharmaceutical application.

4. Quality of Carrageenan from Tropical Seaweed Materials

Carrageenan is a stabilizer, thickener, and gel former in food products. In the non-food industry, carrageenan is used as a mixture for cosmetics, paints, and textiles, and is used in the pharmaceutical industry (Shen and Kuo, 2017). The carrageenan extraction process is done in an alkaline atmosphere

Table 3. Characteristics of Carrageenan Quality

Sample	Location	Results	Sources
Eucheuma spinosum	Nusa penida	Yields: 25.81%, Ash: 29.03%, Gel strength: 32.73 $g.cm^{-1}$	(Diharmi et al., 2017)
Eucheuma spinosum	Sumenep	Yields: 34.81%, Ash: 29.57%, Gel strength: 43.30 $g.cm^{-1}$	(Diharmi et al., 2017)
Eucheuma spinosum	Takalar	Yields: 37.16%, Ash: 28.26%, Gel strength: 54.14 $g.cm^{-1}$	(Diharmi et al., 2017)
Eucheuma cottonii	Bantaeng	Yields: 7.73%, Moisture: 9.84%, Ash: 37.03%, pH: 7.02	(Lestari et al., 2024)
K. alvarezii	Wongsorejo	Yields: 36.11%, Moisture: 11.19%, Ash: 25.79%, Viscosity: 42.33 cP	(Firdaus et al., 2021)
Eucheuma cottonii	Banggai Beach	Yields: 34.51%, Ash: 36.28%, Viscosity: 1.700 cP, Gel strength: 52.37 $g.cm^{-1}$	(Ferdiansyah et al., 2023)
K. alvarezii	Karimun	Yields: 34.3%, Moisture: 6.3%, Ash: 59.4%, Viscosity: 8.20 cP, Gel strength: 94.45 $g.cm^{-1}$	(Manuhara et al., 2016)

using alkaline solutions such as NaOH, $Ca(OH)_2$, or KOH. The use of alkali in this extraction process helps the extraction of polysaccharides to be more perfect and accelerates the elimination of 6-sulfate from monomer units to 3,6-anhydro-D-galactose to increase gel strength and product reactivity towards protein (Campo et al., 2009; Hilliou et al., 2006; Uy et al., 2005). The quality characteristics of carrageenan that researchers have carried out in the last 5 years can be seen in Table 3.

The type of species, cultivation location, and extraction conditions greatly influences the quality of carrageenan produced from seaweed. Some parameters generally used to assess carrageenan quality include yield, ash content, water content, viscosity, gel strength, and pH. Evaluation of these parameters is important to determine the suitability of carrageenan as a raw material in pharmaceutical preparations, especially soft capsules.

Yield analysis in previous studies showed that most of them met the FAO yield standard of a minimum of 25%. Diharmi et al. (2017), Firdaus et al. (2021), Ferdiansyah et al. (2023), and Manuhara et al. (2016) showed that the yield produced met the FAO standard with a yield range of 25 - 37%. According to Diharmi et al. (2017), the difference in carrageenan yield may be due to differences in growing areas. Various factors in the growing regions may physiologically influence carrageenan formation in the seaweed. The difference in environmental conditions, such as water temperature, pH, and salinity in coastal areas of Nusa Penida, Sumenep, and Takalar, may affect carrageenan formation in the seaweed. In addition, the yield of carrageenan can be influenced by the extraction conditions used. Sormin and Masela (2019) stated that carrageenan yield is influenced by several factors, including an increase in pH resulting from the addition of an alkaline solution. Higher temperatures also contribute to increased yield, as elevated heat allows for more efficient carrageenan extraction from seaweed.

Furthermore, alkaline treatment promotes the formation of 3,6-anhydrogalactose during the extraction process. In the study of Lestari et al. (2024), the yield produced was very low. The low yield of carrageenan can be influenced by several factors, such as the use of too high an extraction temperature, which can reduce the yield of carrageenan. The higher extraction temperatures may have resulted in polysaccharide degradation (Webber et al., 2012).

Water content is an essential parameter in determining product stability during storage. Carrageenan with water content that is too high tends to be readily degraded by microbiology and physical factors. Previous research on the characteristics of carrageenan water content shows that it meets the FAO standard, which is a maximum of 12%. The water content of the seaweed used can influence the water content of carrageenan. Carrageenan possesses strong water-binding properties. Its polymer chains can form intertwined double helices, which enable the entrapment of free water molecules. As the concentration of carrageenan increases, a greater amount of water can be immobilized within its polymer network (Hamzah et al., 2021).

Ash content reflects the content of minerals and inorganic salts in carrageenan. High ash content values " can reduce purity and affect the stability of pharmaceutical preparations. Based on previous research data, most have met the FAO ash content standard, which is 15% - 40%. According to Chan et al. (2013), the ash fraction in k-carrageenan consists mostly of macro minerals, such as potassium, sodium, calcium, and magnesium. Ash content is directly proportional to mineral content. The ash content of carrageenan can be affected by several factors. The alkali solution concentration used in carrageenan extraction can affect the ash content of carrageenan. The higher the concentration used, the higher the ash content of the carrageenan produced. Alkali solutions such as NaOH

Table 4. FTIR Characteristics of Carrageenan

Types of Carrageenan	IR Absorption Peak (cm^{-1})	Information	Sources
Kappa carrageenan	3319	OH stretching	(Perumal and Selvin, 2020)
	2930	CH stretching	(Perumal and Selvin, 2020)
	1619	Asymmetric C=O stretching	(Perumal and Selvin, 2020)
	1428	Symmetrical band of COO^-	(Perumal and Selvin, 2020)
	1234	Sulfate stretching of SO	(Perumal and Selvin, 2020)
	1159	Bridge C-O stretching	(Perumal and Selvin, 2020)
	1066	C-O-C stretching	(Perumal and Selvin, 2020)
	920	C-O-C of 3,6 anhydro-o-galactos	(Perumal and Selvin, 2020)
	844	C-O-SO_3 stretching	(Perumal and Selvin, 2020)
	699	Sulfate on C-4 galactose	(Perumal and Selvin, 2020)
Iota carrageenan	3369	O-H stretch	(Ghani et al., 2019)
	2912	C-H stretch	(Ghani et al., 2019)
	1214	ester sulfate O-S-O symmetric vibration	(Ghani et al., 2019)
	1157	C-O bridge stretch	(Ghani et al., 2019)
	1066	C-O stretch	(Ghani et al., 2019)
	927	C-O-C of 3,6 anhydro-o-galactos	(Ghani et al., 2019)
	848	-O-SO_3 stretching vibration at D-galactose-4-sulfate	(Ghani et al., 2019))
	802	-O-SO_3 stretching vibration at D-galactose-2-sulfate (DA2S)	(Ghani et al., 2019)

will adhere to seaweed during the extraction process. The increasing amount of sodium and other minerals attached to seaweed during the extraction process increases the ash content of the carrageenan produced. In addition, the longer the extraction time, the longer the seaweed will contact heat and the extraction solution (Manuhara et al., 2016; Astuti et al., 2017). According to Ferdiansyah et al. (2023), alkaline solutions contain K^+, Na^+, and Ca^{2+}, which are inorganic substances that are not lost during heating. Ash content in carrageenan can derive from macro and micro minerals absorbed or retained in seaweed as a material for carrageenan.

The viscosity of carrageenan is directly related to its ability to form gel and film systems. High viscosity values " indicate a long and complex molecular structure, which is very useful in applications as soft capsule forming agents. The results of previous studies have shown that the viscosity of the carrageenan obtained has met the FAO standard, which is a minimum of 5 cP. According to Astuti et al. (2017), the viscosity of carrageenan can be affected by sulfate levels and is directly proportional to sulfate content. High sulfate content will produce high viscosity, due to the ability of sulfate groups in carrageenan to provide repulsive forces between negative charges along the polymer chain. As a result, the molecular chain becomes stiff, so that viscosity increases. In addition, molecular weight also plays a role in increasing viscosity. The polymer BM shows the average molecular chain length. The high BM of carrageenan causes the distribution of sulfate groups in the polymer chain to become homogeneous, so the repulsive force and viscosity increase (Komersová et al., 2022; Montoro and Francisca, 2019). According to Naseri et al. (2020), low viscosity can be influenced by impurities bound to carrageenan, thus interfering with the extraction solution attacking the seaweed cell wall to release carrageenan, thereby degrading the structure of the carrageenan itself.

Gel strength is one of the critical parameters in soft capsule formulation, because it determines the mechanical strength of the capsule wall. The higher the gel strength value, the better the material's ability to form a stable and non-breakable capsule. The gel strength value produced is by the FAO standard, which states that the gel strength value of carrageenan is 20-500 $g.cm^{-1}$. This shows that the gel strength of carrageenan in previous studies has met the FAO gel strength standard. *K. alvarezii* from Karimun showed the highest gel strength of 94.45 $g.cm^{-1}$, while *E. spinosum* from Nusa Penida had the lowest gel strength of 32.73 $g.cm^{-1}$. However, the data above show that the gel strength of the carrageenan produced is relatively low.

In addition to the physicochemical properties discussed above, carrageenan's FTIR (Fourier Transform Infrared Spectroscopy) characteristics are also crucial for determining its suitability in capsule applications. FTIR analysis provides insights into the functional groups present in carrageenan, such as sulfate esters and 3,6-anhydrogalactose, which directly influence its gelling behavior, solubility, and interaction with other formulation components. Inaccurate functional group composition can result in inconsistent gel strength or poor film-forming ability, affecting soft capsules' integrity, elasticity, and disintegration performance. Therefore, FTIR characterization is essential to ensure carrageenan's consistency and functional reliability in pharmaceutical capsule formulations. The FTIR characteristics of carrageenan are presented in Table 4.

The FTIR analysis results showed that both kappa and iota carrageenan have typical main functional groups, such as hydroxyl (O–H), methylene (C–H), sulfate (SO_3^-), and 3,6-anhydrogalactose groups, which are characteristic of the carrageenan structure. Kappa carrageenan, as reported by Perumal and Selvin (2020), showed a typical absorption peak at 920 cm^{-1} indicating the presence of 3,6-anhydro-α-D-galactose groups - an important group in the formation of a strong gel structure. The peaks at 844 and 699 cm^{-1} indicate the presence of sulfate bonds that contribute to solubility and gel-forming capacity. Similarly, iota carrageenan analyzed by Ghani et al. (2019) showed a similar absorption pattern, including peaks at 927 cm^{-1} and 848 cm^{-1}, confirming the presence of sulfate at an important position in the galactose structure.

Iota carrageenan has more sulfate groups, as seen from the additional peak at 802 cm^{-1} (sulfation at the 2-galactose position). This makes iota carrageenan more soluble and produces a softer and more elastic gel. Kappa carrageenan has a stiffer structure due to its lower sulfate level and high proportion of 3,6-anhydrogalactose. As a result, it forms a strong and brittle gel, suitable for hard capsules or solid matrices.

Carrageenan types can be classified according to the presence of 3,6-anhydro bridges on the four-membered galactose residue and the position and number of sulfate groups (Vandanjon et al., 2023). FTIR spectra reflect the unique structural features of carrageenan, which consists of repeating disaccharide units made up of 3-linked D-galactopyranose (G-units) and either 4-linked D-galactopyranose (D-units) or 4-linked 3,6-anhydro-D-galactopyranose (DA-units). The classification of carrageenan is based on the presence of the 3,6-anhydro bridge on the 4-linked galactose unit and the number and position of sulfate groups attached to the sugar backbone. These structural differences give rise to distinct FTIR absorption patterns for each carrageenan type. Traditionally, carrageenans are categorized as kappa (κ; G4S–DA), iota (ι; G4S–DA2S), and lambda (λ; G2S–D2S,6S). Their respective sulfate substitutions and the presence or absence of anhydro bridges influence their chemical properties and functional behavior in applications. Additionally, the precursors of kappa and iota carrageenan—known as mu (μ) and nu (ν), respectively-contain sulfate groups at the C-6 position (D6S), which can be converted into DA-units through alkaline treatment. These structural elements are typically detected by characteristic FTIR peaks, particularly in the regions corresponding to sulfate stretching and C–O–C vibrations, which are critical for assessing the type and quality of carrageenan (Boulho et al., 2017).

Each type of carrageenan exhibits specific FTIR absorption bands related to the position of sulfate esters and the presence of 3,6-anhydro bridges. The presence of sulfate esters is confirmed by firm peaks near 1240 cm^{-1} (S=O stretching), while the appearance of bands around 930 cm^{-1} and 1070 cm^{-1} indicates the presence of 3,6-anhydrogalactose (DA), which is essential for gel formation. The classification of carrageenan types can be further refined through FTIR spectral interpretation. According to literature, a peak at approximately 1240 cm^{-1} corresponds to sulfate esters and is typical of iota, kappa, and nu carrageenan. A band near 1070 cm^{-1} is linked to C–O stretching in DA units, while the 930 cm^{-1} peak is a strong marker for DA-specific vibrations in iota and kappa. Furthermore, 905 cm^{-1} is unique to iota carrageenan, indicating sulfate at C-2 of DA (DA2S), while 867 cm^{-1}, 825–830 cm^{-1}, and 815–820 cm^{-1} are characteristic of nu carrageenan, related to sulfation at various positions of galactose. The 845 cm^{-1} band, found in all three types, is associated with C-4 sulfation on galactose (G4S) (Vandanjon et al., 2023).

5. Application of Carrageenan to Capsule Shells

The quality of carrageenan from tropical seaweed in Indonesia shows that the carrageenan produced meets FAO standards. Carrageenan is mainly used in the pharmaceutical sector to make capsule shells. The use of carrageenan in making capsule shells functions as the leading gel former, which provides structure and strength to the capsule shell. Besides carrageenan, it is usually used with additional ingredients such as starch, glycerin, or sorbitol to produce physical and mechanical properties. Capsules are divided into hard capsules and soft capsules. According to the Ministry of Health of the Republic of Indonesia (2020), the difference between hard capsules and soft capsules is that hard capsules consist of a body and lid, are available in empty form, the contents are usually solid. Still, they can also be liquid, can be used orally, and have only one shape, while soft capsules are one unit; it is always filled, usually liquid or solid, can be oral, vaginal, rectal, and topical, and comes in various shapes. According to Zhou et al. (2023), the incorporation of plasticizers such as glycerol and sorbitol is crucial in enhancing the mechanical properties and stability of polysaccharide-based soft capsules, indicating the significance of these additives in capsule formulation. Images of hard and soft capsules can be seen in Figure 1.

Carrageenan, especially iota and kappa types, has been widely explored in manufacturing soft and hard capsules. Data shows that every kind of carrageenan produces different capsule characteristics, depending on the polymer structure and application form. In the manufacture of soft capsules, carrageenan can form a gel that is quite elastic and flexible when combined with other components. However, to produce capsules with optimal mechanical properties (flexible, not brittle, and not easily broken), carrageenan needs to be combined with additional materials. In the study of capsule shell manufacture by Perwatasari et al. (2025), 1.5% iota carrageenan was used with additional materials such as hydroxypropyl starch, glycerol, and sorbitol. Zheng et al. (2023) used kappa carrageenan, sodium alginate, and carboxymethyl starch. In their study, Pudjiastuti et al. (2020) combined κ-carrageenan with starch and kappa

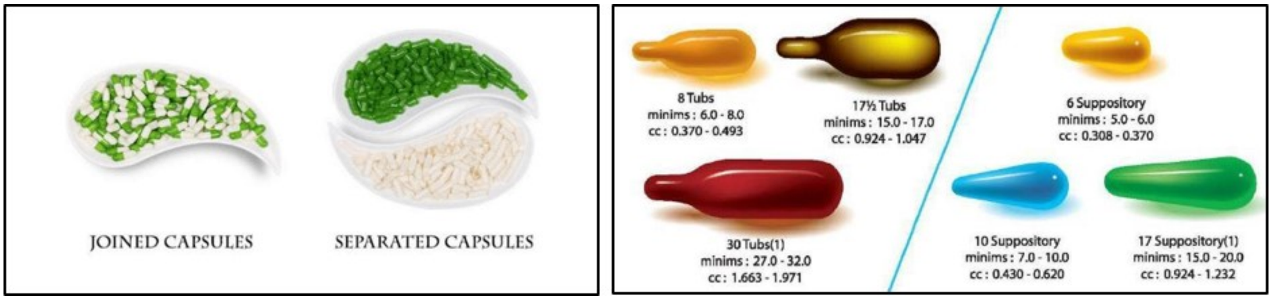
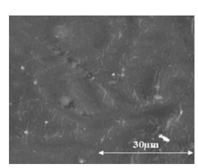
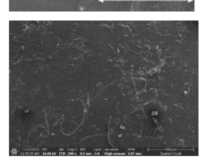


Figure 1. Hard Capsules (Left) and Soft Capsules (Right) (Hij Machinery, 2019)

Table 5. Characteristics of Carrageenan Capsules

Parameter	Types of Carrageenan	Types of Capsules	Results	Sources
Length	Iota carrageenan	Soft capsule	13.56 mm	(Perwatasari et al., 2025)
	Kappa carrageenan	Hard capsule	22.56 mm	(Fauzi et al., 2020)
Width	Iota carrageenan	Soft capsule	7.48 mm	(Perwatasari et al., 2025)
	Kappa carrageenan	Hard capsule	7.18 (body), 7.37 (cap) mm	(Fauzi et al., 2020)
Heavy	Iota carrageenan	Soft capsule	0.49 g	(Perwatasari et al., 2025)
	Kappa carrageenan	Hard capsule	0.12 g	(Fauzi et al., 2020)
Leakage time	Iota carrageenan	Soft capsule	25.89 min	(Perwatasari et al., 2025)
Disintegration	Iota carrageenan	Soft capsule	66.44 min	(Perwatasari et al., 2025)
	Kappa carrageenan	Soft capsule	15 min	(Zheng et al., 2023)
	Kappa carrageenan	Hard capsule	36.21 min	(Soraya et al., 2025)
	Kappa carrageenan	Hard capsule	18.47 min	(Fauzi et al., 2020)
	Kappa carrageenan	Hard capsule	12.80 min	(Pudjiastuti et al., 2020)
	Kappa carrageenan	–	25.79 min	(Pudjiastuti et al., 2020)
Tensile strength	Iota carrageenan	Soft capsule shell sheet	2.3 Mpa	(Hidayat et al., 2024)
Stickiness	Iota carrageenan	Soft capsule shell sheet	1500 gf, "1,755 kg/force"	(Hidayat et al., 2024) and (Djafar et al., 2024)
Viscosity	Iota carrageenan	Soft capsule shell sheet	1800 cP	(Hidayat et al., 2024)
Scanning Electron Microscopy (SEM)	Kappa carrageenan	Hard capsule shell		(Fauzi et al., 2020)
	Iota carrageenan	Soft capsule shell		(Perwatasari et al., 2025)

carrageenan with alginate. Fauzi et al. (2020) combined kappa carrageenan with maltodextrin (6:1) and added sorbitol. Soraya et al. (2025) used 22.5 g of kappa carrageenan, primogel, and Tween 80. Djafar et al. (2024) combined carrageenan with starch, glycerol, and sorbitol. Hidayat et al. (2024) used a combination of iota carrageenan, modified starch, and glycerol. Previous research regarding the characteristics of the capsules produced can be seen in Table 5.

The process for making hard and soft capsule shells is different. Hard capsule shells can be dipped by mixing carrageenan with distilled water and stirring them using a magnetic stirrer at a temperature of 95°C until they are homogeneous. Then the plasticizer is added to the solution and stirred. Next, the hot plate is turned off, and printing begins. The molding process is carried out by inserting the capsule shell tool into the solution for 3 seconds, then removing and drying it. After drying, the capsule is released from the mold and cut to the cap and shell body size. Unlike hard capsules, divided into body and cap, soft capsules are made, filled, and sealed in one process. When making soft capsules, the gel strength required is lower than that of hard capsules (Rowe et al., 2009). In a beaker, soft capsule shell films are made by mixing water with plasticizers (glycerol and sorbitol) and carrageenan. The mixture was heated using a homogenizer for 30 minutes. After that, starch is added, stirred, and heated to a temperature of 95°C. The dough homogenized to a milky white color tends to be clear, printed on 1.5 mm thick acrylic, and the surface is smoothed (Djafar et al., 2024).

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Iota carrageenan-based soft capsules have average dimensions of 13.56 mm in length and 7.48 mm in width, weighing 0.49 g. The leakage and disintegration times were quite long, 25.89 minutes and 66.44 minutes, respectively, indicating good structural resistance to environmental conditions (Perwatasari et al., 2025). These characteristics are reinforced with a tensile strength of up to 2.3 MPa and an adhesion level (stickiness) of up to 1,755 gf, indicating flexibility and mechanical strength that is close to or even equal to gelatin (Hidayat et al., 2024; Djafar et al., 2024). Disintegration that exceeded the standard in the Perwatasari et al. (2025) study can be caused by the solid matrix formed by modified cassava starch combined with iota carrageenan, which provides structural integrity and prolongs the breakdown process.

According to Hidayat et al. (2024), the more glycerol is used, the tensile strength value of the soft capsule shell film will increase. The results obtained have met the Japanese Industrial Standard, namely a minimum tensile strength value of 0.39 MPa. The mixture of iota carrageenan with plasticizer showed better thermal stability and tensile strength properties. In addition, increasing the amount of glycerol used will increase the stickiness and viscosity of the capsule shell film. The increasing composition of iota carrageenan, starch, and glycerol can increase the viscosity of the capsule shell film.

On the other hand, kappa carrageenan is more widely applied in hard capsules, with longer dimensions (22.56 mm) and varying disintegration times depending on the formulation, ranging from 12.80 to 36.21 minutes (Fauzi et al., 2020; Pudjiastuti et al., 2020; Soraya et al., 2025). In the study of Soraya et al. (2025), an evaluation was conducted related to the dynamics of disintegration of seaweed capsules containing several additional materials, such as Polyvinylpyrrolidone, Primogel, Sodium Croscarmellose, and Sodium Carboxymethylcellulose. The results showed that using primogel in soft capsules would result in lower capsule swelling ability, resulting in faster destruction caused by reduced water retention and a less water-saturated matrix.

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SEM (Scanning Electron Microscopy) characteristics of carrageenan-based capsule shells conducted by Fauzi et al. (2020) showed the presence of pores on the surface of the film, while on the surface of the gelatin capsule shell film there were no pores at the same magnification scale, so it can be concluded that the pores of the carrageenan-based capsule shell are larger than the pores of the gelatin capsule shell. The nature of the carrageenan hydrogel causes these pores. In addition, the more elastic mechanical properties of gelatin capsules can be seen from the minimal cracks or break patterns in the SEM image. In contrast, carrageenan capsules tend to be more fragile and show more precise indications of microcracks. This difference affects stability, release of active substances, and compatibility in pharmaceutical and supplement applications.

These data indicate that both iota and kappa carrageenan can produce capsules with competitive physical and mechanical properties, even without using gelatin. With formulation optimization, carrageenan from tropical seaweed can qualify as a base material for soft capsules, especially in terms of tensile strength, viscosity, and shape stability.

6. Challenges Associated with Carrageenan Soft Capsules

In the development of plant-based soft capsules, selecting the appropriate type of carrageenan is crucial to the success of the formulation. Carrageenan consists of various kinds-namely, kappa, iota, and lambda-each with distinct structural and rheological properties. Studies conducted by Ock et al. (2020) and Oishi et al. (2018) have shown that iota-carrageenan is the most suitable type for soft capsule production. Iota-carrageenan is extracted through alkaline treatment from the red seaweed *Eucheuma denticulatum* and possesses a structure rich in sulfate groups-particularly 4-sulfate on D-galactose and 2-sulfate on 3,6-anhydro-D-galactose-which contributes to the formation of elastic and flexible gels (Necas and Bartosikova, 2013).

In contrast, kappa-carrageenan is more commonly used in hard capsule formulations. Previous studies have indicated that kappa-carrageenan, derived from seaweed, is a promising non-gelatin alternative for hard capsules due to its gel strength and viscosity comparable to gelatin (Soraya et al., 2024). However, the rheological characteristics required for soft capsules are significantly more demanding, as they require gelling agents with higher viscosity and elasticity (Naharros-Molinero et al., 2024).

Unlike kappa-carrageenan, which forms brittle and rigid gels, iota-carrageenan produces softer and more elastic gels (Alves et al., 2010)-a desirable feature for soft capsules that demand high flexibility and adequate mechanical strength (Hilliou, 2021). Thus, iota-carrageenan is considered more appropriate for use as the primary material in soft capsule shells than other carrageenan types.

Despite these advantages, using iota-carrageenan in soft capsule formulations still encounters several technical and functional challenges, such as high viscosity, slow disintegration time, poor solubility due to high molecular weight, and suboptimal mechanical strength. Carrageenan, particularly at effective concentrations, tends to have high viscosity, complicating soft capsules' molding and filling processes. Excessive viscosity may also hinder drug release from the capsule. A proposed solution is molecular depolymerization. For instance, Tecson et al. (2021) demonstrated that ultrasonic-assisted depolymerization significantly reduced carrageenan's molecular weight and viscosity, up to 96.33% from its initial molecular weight, thereby improving flow properties and accelerating disintegration.

Carrageenan-based capsules also tend to exhibit longer disintegration than gelatin capsules (Gullapalli and Mazzitelli, 2017), potentially delaying drug release and absorption. One practical approach to address this is bacterial fermentation, as Li et al. (2024) demonstrated, using marine bacteria *Shewanella* sp. to depolymerize iota-carrageenan. After fermentation, the apparent viscosity of the carrageenan was reduced by up to 84.10%, contributing to enhanced solubility and faster disintegration.

The complex structure of carrageenan also limits its solubility, hindering active compounds' efficient release in the digestive tract (Song et al., 2023). In addition to depolymerization, formulation strategies such as the addition of co-polymers or solubilizing agents—such as sodium alginate, glycerol, and sorbitol—can improve solubility and facilitate a more uniform distribution of active ingredients within the gel matrix, as reported by Perwatasari et al. (2025). Furthermore, soft capsules require shells that are both flexible and mechanically robust. Unmodified carrageenan gels may be too brittle or weak. The addition of film-forming agents and cross-linkers such as maltodextrin (Fauzi et al., 2020) has been shown to enhance the gel strength of kappa-carrageenan. Similarly, combining carrageenan with modified starch or glycerol can improve capsule elasticity and mechanical stability.

7. Future Research: Using Seaweed as A Substitute for Gelatin In Soft Capsule Shells

Exploration of the development of capsules with seaweed carrageenan to replace gelatin is progressing. Several previous studies have observed how tropical seaweed in Indonesia can produce carrageenan of good quality and meet standards. The quality of the carrageenan produced can be influenced by the type of seaweed used, the age at which the seaweed is harvested, the location of the seaweed habitat, and the extraction process used, including the materials, temperature, and time used during extraction. The material used in the seaweed extraction process is an alkaline solution. The quality of the carrageenan produced can be applied as a thickener and gelling agent to be used as a substitute for gelatin.

Research on making capsule shells from carrageenan has been widely carried out. If we look at the application of carrageenan in hard capsule shells, it meets the standards, and the quality produced is similar to commercial capsules. Several researchers have researched making soft capsule shell films. Soft capsule shells usually use carrageenan, starch, glycerol, and, in some studies, even sorbitol. The type of carrageenan that can be used in making soft capsule shells is iota carrageenan. Iota carrageenan produced by previous researchers has shown good carrageenan quality and meets standards. So it can be used as raw material to make soft capsules. Future research should be directed at developing plant-based soft capsules primarily from high-quality, low-cost seaweed with little or no contaminants (chemical or microbial). An alternative to producing soft capsule shells for future research is engineering the depolymerization process of iota carrageenan and modifying kappa carrageenan, such as iota carrageenan. Carrageenan soft capsule shells have comparable properties to commercial soft capsule shells, thus showing good potential as an alternative to gelatin soft capsule shells.

8. CONCLUSIONS

Iota carrageenan derived from tropical seaweed shows strong potential as an alternative to gelatin in soft capsule formulations due to its ability to form elastic gels, biocompatibility, and capacity to produce flexible films. However, key challenges remain, including high viscosity, limited solubility, and slow disintegration. Studies have demonstrated that structural modification (via fermentation or depolymerization), the addition of plasticizers, and blending with other polymers such as modified starch can significantly enhance the mechanical and functional properties of carrageenan-based films. With optimized formulation and processing, carrageenan holds great promise as a halal, environmentally friendly, and competitive material for plant-based soft capsule development in modern drug delivery systems.

9. ACKNOWLEDGEMENT

The authors are very grateful to the National Research and Innovation Agency (BRIN) for funding the housing program at the BRIN research and agricultural organization.

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