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EVALUATION OF SEAWEED-DERIVED HYDROCOLLOIDS AS FUNCTIONAL REPLACEMENTS FOR GELATIN IN GUMMY PRODUCTION

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Abstract: *Gummies are confectionery products that rely on hydrocolloids to stabilize their formulations by forming gel networks that entrap high-moisture sugar syrups. These hydrocolloids play an essential role in determining the products' texture, appearance, and flavour release. This study investigated the potential of replacing animal-derived gelatin with seaweed-derived hydrocolloids, namely agar, carrageenan, and alginate, in gummy confectionery formulations. Four formulations were prepared: a gelatin control (F1), an agar-based formulation (F2), a carrageenan-based formulation (F3), and an alginate-based formulation (F4). The formulations were evaluated in terms of their physicochemical properties, texture profile analysis (TPA), syneresis, and microstructural characteristics using scanning electron microscopy (SEM). The results showed that the seaweed-derived hydrocolloids maintained relatively stable acidic pH values (3.4–3.5) and *did not produce statistically significant differences in colour lightness (L)**. Moisture content ranged from 15.8% to 18.4%, with the gelatin formulation exhibiting the highest value and the alginate*

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formulation the lowest. Syneresis testing revealed higher water release in the agar- and alginate-based formulations after 14 days of storage, indicating comparatively lower water-retention stability. In contrast, the gelatin and carrageenan formulations demonstrated lower syneresis values, suggesting better moisture retention during storage. Textural analysis showed that carrageenan achieved a gel strength of 245 g Bloom, which was relatively close to that of gelatin (260 g Bloom). Carrageenan also exhibited relatively high springiness and cohesiveness, indicating its potential to provide a balanced textural profile comparable to gelatin. Overall, the findings identify carrageenan as the most promising seaweed-derived hydrocolloid alternative to gelatin among the formulations investigated. The use of carrageenan, particularly that derived from Eucheuma cottonii, may contribute to the development of plant-based and halal-compliant gummy products while supporting the sustainable utilization of marine resources. Further formulation optimization and processing studies are required to establish its technical and commercial feasibility.

Keywords: *Seaweed-derived Hydrocolloids, Carrageenan, Agar, Alginate, Gelatin Substitution, Gummy Confectionery, Physicochemical Properties.*

Introduction

Jelly confectionery is a soft, gel-like product formulated using hydrocolloid agents such as agar, gum, pectin, starch, carrageenan, and gelatin. These hydrocolloids play an important role in modifying the texture and structural properties of confectionery products, particularly in determining their chewiness and elasticity (Mustika et al., 2021). Jelly candies are widely consumed because of their distinctive elastic texture and appealing sensory characteristics. Traditionally, gelatin has been the preferred gelling agent in confectionery production because of its ability to form elastic, transparent, and chewy gel structures. However, the animal origin of gelatin has raised dietary, ethical, and religious considerations among certain consumer groups, contributing to increased interest in plant-based alternatives, particularly for halal-compliant and vegetarian food applications.

This growing interest has encouraged the exploration of seaweed-derived hydrocolloids, particularly agar, carrageenan, and alginate, as potential alternatives to animal-based gelatin. These marine polysaccharides are renewable biopolymers with the ability to form gel structures with different textural and stability characteristics. Carrageenan, for example, is a sulphated polysaccharide extracted from red seaweed, including Eucheuma cottonii, and is widely used in food products as a stabilising, thickening, and gelling agent (Djaeni et al., 2015). Its application in jelly and gummy confectionery is particularly relevant because its gel-forming properties can contribute to the development of the desired product texture. Nevertheless, the functional performance of carrageenan may be influenced by its formulation and interactions with other ingredients, while the characteristic flavour of seaweed may also affect the sensory acceptability of the final product (Amalia et al., 2021). Therefore, the suitability of seaweed-derived hydrocolloids as gelatin substitutes needs to be assessed beyond their basic gel-forming capabilities.

Previous studies have provided evidence of the potential of alternative hydrocolloids in gummy confectionery, although their formulations and evaluation parameters have varied. DeMars and Ziegler (2001), for instance, investigated gelatin–high-methoxyl pectin gummy systems using gelatin concentrations of 3.0%, 4.5%, and 6.0%, combined with pectin concentrations ranging from 0% to 1.5%. Their study evaluated instrumental texture, microstructural characteristics,

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and sensory properties, demonstrating that changes in hydrocolloid composition influenced gel fracture behaviour, chewiness, and flavour perception. More recently, Song et al. (2022) examined κ-carrageenan-based vegan gummy candies by incorporating different concentrations of carboxymethyl cellulose (CMC). Their findings showed that a formulation containing 20 g/kg κ-carrageenan and 4 g/kg CMC produced a more flexible gummy structure, reduced brittleness, and limited water seepage during storage. However, increasing the CMC concentration to 8–12 g/kg weakened the gel structure and accelerated syneresis. These findings demonstrate that the functional performance of hydrocolloids is dependent not only on the type of gelling agent but also on formulation composition and ingredient interactions.

Despite these developments, a comparative assessment of gelatin, agar, carrageenan, and alginate within gummy formulations prepared under consistent processing conditions remains necessary. Previous investigations have focused on selected hydrocolloid combinations or individual formulation systems, making direct comparisons between different gelling agents difficult. Consequently, important functional attributes, including moisture retention, water activity, gel strength, hardness, springiness, cohesiveness, syneresis, and microstructural characteristics, require further evaluation within a comparable experimental framework. In particular, it remains important to establish whether agar, carrageenan, and alginate can provide physicochemical and textural characteristics comparable to those of conventional gelatin-based gummy products. A systematic comparison involving four formulations gelatin as the control, agar, carrageenan, and alginate under standardised preparation and processing conditions would therefore provide more consistent evidence of their relative functional performance. Accordingly, this study evaluates the physicochemical, textural, microstructural, and storage stability properties of these four formulations to identify the potential of seaweed-derived hydrocolloids as functional replacements for animal-based gelatin in gummy production.

Literature Review

The increasing demand for plant-based and sustainable food products has encouraged research into the functional applications of marine-derived hydrocolloids as alternatives to animal-based gelatin in gummy confectionery. Gelatin remains a widely used gelling agent because of its ability to form thermoreversible gel networks with desirable elasticity, transparency, and chewiness. Nevertheless, agar, carrageenan, and alginate have attracted attention because of their distinct gel-forming mechanisms and functional properties. Agar forms gel structures through the aggregation of double-helical chains, whereas alginate forms networks through ionic cross-linking, commonly involving calcium ions. In contrast, κ-carrageenan undergoes coil-to-helix transitions followed by helix aggregation, producing gel networks whose properties are influenced by ion concentration and polymer interactions (Campo et al., 2009). These differences in molecular structure and gelation mechanisms influence the firmness, elasticity, cohesiveness, and water-retention properties of the resulting products. Liu et al. (2022) further highlighted the importance of polymer interactions, ionic conditions, and moisture migration in determining the functional performance of marine-derived hydrocolloids in food applications.

Previous studies have also demonstrated the potential of hydrocolloid combinations in improving the structural and physicochemical properties of food-related biopolymer systems. Hunashyal et al. (2026), for example, investigated gelatin/κ-carrageenan composite films reinforced with cellulose nanocrystals and reported improvements in mechanical strength and moisture-related properties. Similarly, Prasetyaningrum et al. (2021) examined sodium alginate/κ-carrageenan edible films and demonstrated that the incorporation of κ-carrageenan

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and calcium ions influenced the mechanical properties and flexibility of the resulting films. Although these investigations provide useful insights into polymer interactions, moisture retention, and structural stability, their findings should be interpreted within the context of film and packaging applications rather than assumed to represent the behaviour of gummy confectionery directly. The differences in formulation, moisture content, processing conditions, and product structure indicate the need for further evaluation using actual gummy formulations. Texture is an important quality attribute in gummy confectionery because it determines the physical response of the product during biting and chewing. Parameters such as hardness, springiness, cohesiveness, gumminess, and chewiness are commonly used to characterise the textural properties of gel-based confectionery. However, instrumental measurements alone may not fully represent the sensory experience perceived by consumers. McKenzie et al. (2022) investigated the sensory characteristics of model confectionery gels formulated using gelatin, ι-carrageenan, κ-carrageenan, and konjac glucomannan. Their descriptive analysis demonstrated that different gelling agents produced distinct sensory profiles, including chewiness, creaminess, mouthcoating, and melt-in-mouth characteristics. The researchers also identified relationships between instrumental texture parameters and sensory perceptions, whereby cohesiveness and gumminess were associated with melt-in-mouth and jiggly texture characteristics. These findings demonstrate that instrumental texture analysis and sensory evaluation provide complementary information when assessing the quality of confectionery gels.

Consumer acceptance is also influenced by the interaction between texture, taste, flavour, and other sensory attributes. Izaber-Ludwig et al. (2026) examined the sensory characteristics and consumer acceptance of commercial fruit gummy candies involving 147 consumers and 12 products. Using sensory characterisation and a nine-point hedonic scale, the study found that texture, particularly hardness and stickiness, was an important determinant of overall liking, alongside taste. The findings also indicated that consumer preferences varied according to the textural characteristics and gelling agents used in the products. In a related investigation, Rawat et al. (2024) evaluated vegan gummies developed using plant-based hydrocolloids and assessed texture, appearance, flavour, and overall acceptability through a nine-point hedonic scale involving semi-trained judges. Their study illustrates the importance of evaluating several sensory attributes rather than relying exclusively on instrumental texture measurements. More recently, Rawat et al. (2026) examined agar-agar and guar gum-based vegan gummies and evaluated texture, appearance, flavour, and overall acceptability using a sensory panel and a nine-point hedonic scale. Collectively, these studies highlight the importance of combining instrumental and sensory assessments to understand the quality and consumer acceptability of alternative gummy formulations.

Despite the growing body of research on alternative hydrocolloids, comparative evidence involving gelatin, agar, carrageenan, and alginate in gummy formulations remains limited. Existing studies have examined individual hydrocolloids, selected hydrocolloid combinations, or biopolymer films, with variations in formulation composition and processing conditions. Consequently, direct comparisons of their physicochemical characteristics, gel strength, textural properties, moisture retention, syneresis, and microstructural features remain challenging. Furthermore, the relationship between instrumental texture measurements and the sensory characteristics of gummy products requires careful consideration when identifying suitable gelatin replacements. Therefore, a systematic comparison of four gummy formulations comprising gelatin as the control, agar, carrageenan, and alginate as alternative gelling agents is important for evaluating their relative functional performance under consistent preparation

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and processing conditions. Such an approach provides a basis for understanding the suitability of seaweed-derived hydrocolloids as potential functional replacements for animal-based gelatin in gummy confectionery production.

Materials and Methods

In this study, four gummy systems were investigated through a systematic evaluation of their physicochemical properties and sensory characteristics using an established methodology for comparative gummy formulation. The formulations comprised a gelatin control (F1), an agar-based formulation (F2), a carrageenan-based formulation (F3), and an alginate-based formulation (F4). Moisture content, pH, water activity, gel strength, colour, and texture profile analysis (TPA) were evaluated using standard analytical procedures, while syneresis was measured after 14 days of storage under ambient conditions. The morphology of the films was also examined using scanning electron microscopy (SEM) to provide morphological information for comparison with findings from recently published studies on other biodegradable films. For example, Hunashyal et al. (2026) investigated the morphological characteristics of biopolymeric films.

Similarly, Prasetyaningrum et al. (2021) investigated the physicochemical, morphological, mechanical, and functional properties of alginate/κ-carrageenan-based edible films incorporating clove essential oil, including their antioxidant activity and surface morphology as observed using SEM. These studies provide a methodological reference for the characterization of polysaccharide-based films. By considering these previous studies, the present work adopts an established approach to the preparation and characterization of gummy formulations while providing a comparative evaluation of four hydrocolloid systems under the same experimental conditions. This comparison contributes to understanding the potential of seaweed-derived hydrocolloids as alternatives to gelatin in gummy production and their relevance to the development of sustainable food products.

Findings and Discussion

The physicochemical characterization of the four gummy formulations, namely gelatin (F1), agar (F2), carrageenan (F3), and alginate (F4), revealed trends consistent with established hydrocolloid principles and recent developments in polysaccharide-based food systems. The moisture content ranged from 15.8% to 18.4%, while the water activity of the seaweed-based formulations was lower (0.68–0.69) than that of the gelatin formulation (0.72). These findings suggest that the incorporation of marine-derived hydrocolloids may influence water distribution and contribute to the physicochemical stability of gummy matrices. Hunashyal et al. (2026) reported that intermolecular interactions in κ-carrageenan–gelatin systems influenced moisture regulation and network reinforcement. Similarly, Prasetyaningrum et al. (2021) demonstrated the potential of alginate/κ-carrageenan composites to influence water entrapment and the physicochemical properties of edible films. Although these studies focused on biopolymeric films rather than gummy products, their findings provide relevant insights into the interactions between polysaccharides and water. Marine polysaccharides are also known for their water-binding properties, which may reduce the availability of free water for microbial growth and consequently contribute to improved product stability (Gómez-Estaca et al., 2009). In addition, the pH values remained relatively consistent across the formulations (3.4–3.5), suggesting that hydrocolloid substitution did not substantially alter the acidic conditions of the gummy systems.

Colour analysis (L*) showed no statistically significant differences among the formulations ($p > 0.05$), indicating that replacing gelatin with the tested hydrocolloids did not produce a

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measurable change in lightness. This finding is relevant because colour and appearance are important visual attributes that may influence consumers' initial perceptions of food products. However, syneresis testing revealed differences in water release during storage. After 14 days, the agar (3.8%) and alginate (4.1%) formulations exhibited higher syneresis values than the gelatin (2.4%) and carrageenan (2.9%) formulations. These findings suggest that the agar- and alginate-based matrices had comparatively lower water-retention stability under the storage conditions used in this study. In contrast, the lower syneresis values observed in the gelatin and carrageenan formulations indicate better water retention over the 14-day storage period. The comparatively low syneresis of the carrageenan formulation suggests its potential to maintain the physical stability of gummy products during storage.

The textural analysis further highlighted the potential of carrageenan as a gelatin alternative. The gel strength of the carrageenan-based formulation was 245 g Bloom, which was relatively close to that of the gelatin formulation (260 g Bloom). This similarity suggests that carrageenan may provide gel strength comparable to gelatin under the formulation conditions examined. This finding is consistent with the gelation mechanisms described by Campo et al. (2009), who explained that κ-carrageenan forms structured gel networks through coil-to-helix transitions and subsequent aggregation, particularly in the presence of suitable ions. These structural mechanisms contribute to the formation of firm gel networks. Agar and alginate produced firmer matrices than gelatin, which may be associated with their respective gelation mechanisms involving double-helix formation and ionic cross-linking. Although these hydrocolloids produced functional gel structures, their textural characteristics may require further optimization to improve elasticity and reduce brittleness.

The texture profile analysis (TPA) showed that agar (3.90 N) and alginate (4.10 N) recorded the highest hardness values, whereas carrageenan exhibited moderate hardness (3.40 N), together with relatively high springiness (0.84) and cohesiveness (0.82). These values were relatively close to those of the gelatin formulation in terms of springiness (0.89) and cohesiveness (0.85). The findings suggest that carrageenan may provide a more balanced textural profile, combining moderate hardness with relatively high springiness and cohesiveness. Taken together, these results indicate that carrageenan can produce a gel structure with characteristics comparable to gelatin while maintaining textural properties that may be desirable in gummy products.

The analysis of variance (ANOVA) was used to examine differences among the four formulations in terms of gel strength, hardness, and springiness. The results indicated statistically significant differences among formulations for the measured textural parameters (the exact p-values should be reported here). Although carrageenan did not produce exactly the same textural profile as gelatin, its relatively similar springiness and cohesiveness suggest functional potential as a gelatin substitute. These findings were also illustrated by the radar plot, which showed overlapping profiles for F1 and F3 across selected textural parameters. In contrast, the agar- and alginate-based formulations may require further formulation adjustments to improve elasticity and reduce excessive firmness or brittleness.

The microstructural observations provide an additional perspective on the structural characteristics of the formulations. The gelatin matrices were described as dense, although microcracks were also observed in the SEM images. Such features may influence the structural integrity of the material; however, their implications for the stability of the gummy products require further evidence. Pouralkhas et al. (2023) reported microstructural characteristics of

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biopolymeric films, which may provide a point of comparison for interpreting morphological features in polysaccharide-based materials. Carrageenan, on the other hand, was associated with a gel network that demonstrated relatively favourable textural characteristics, particularly in terms of springiness and cohesiveness. These findings support the potential of carrageenan as a gelatin alternative, particularly when a balance between gel strength and textural properties is required.

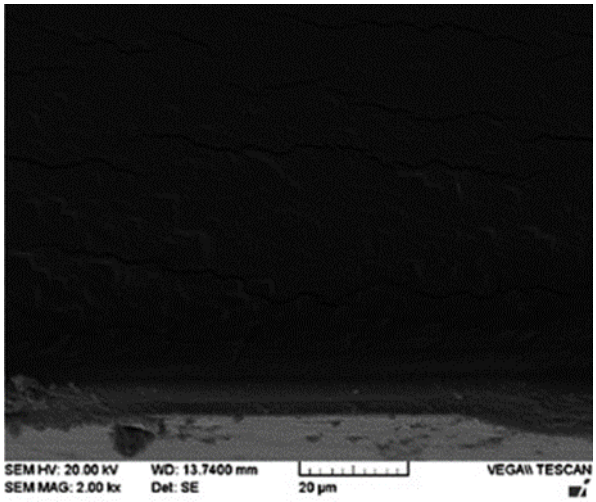


Figure 1: The SEM image of the pure gelatin film (Pouralkhas et al., 2023).

Conclusion

This study demonstrates the potential of seaweed-derived hydrocolloids as functional alternatives to animal-derived gelatin in gummy confectionery systems, with carrageenan emerging as the most promising alternative among the formulations investigated. The carrageenan-based formulation exhibited physicochemical and textural characteristics relatively comparable to those of the gelatin control, particularly in terms of gel strength, springiness, and cohesiveness. These findings suggest that carrageenan can form a gel network with a balanced combination of firmness and elasticity, which may contribute to the desirable textural characteristics of conventional gelatin-based gummies. In contrast, although the agar- and alginate-based formulations demonstrated gel-forming capabilities, they exhibited higher hardness and syneresis values, suggesting limitations in maintaining the desired textural balance and water retention during storage. Therefore, further optimization of hydrocolloid combinations and plasticizer concentrations may help improve the textural properties and overall performance of these formulations.

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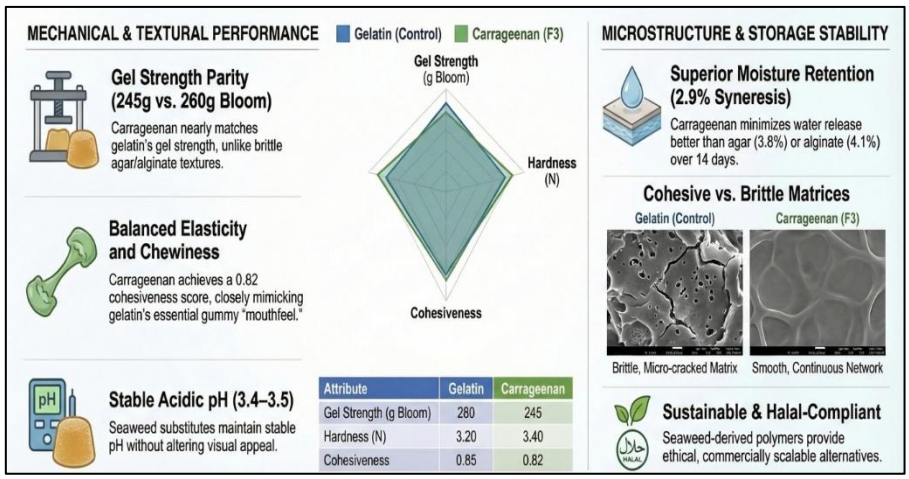


Figure 2: Summary of the main findings of the study

The potential of carrageenan as a gelatin alternative extends beyond its functional properties and may also offer wider technological and socio-economic benefits. The use of seaweed-derived hydrocolloids is relevant to the growing interest in plant-based, halal-compliant, and sustainable food ingredients. In particular, carrageenan derived from Eucheuma cottonii offers opportunities for adding value to seaweed resources, particularly in regions where seaweed cultivation is an established economic activity. Future research should focus on developing optimized combinations of hydrocolloids, characterizing locally available seaweed species, and conducting pilot-scale processing studies to evaluate the technical feasibility, production efficiency, and economic viability of these alternatives. Overall, seaweed-derived hydrocolloids, particularly carrageenan, demonstrate promising potential for replacing animal-derived gelatin in gummy confectionery production, subject to further formulation development and process optimization.

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